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No. 313

STRUCTURAL METHODS EMPLOYED BY
THE SCHÜTTE-LANZ AIRSHIP COMPANY.

By Chief Engineer Gentzcke of the S-L Airship Company.

From "Zeitschrift für Flugtechnik und Motorluftschiffahrt,"
May 15, 1924.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 313.

STRUCTURAL METHODS EMPLOYED BY THE SCHÜTTE-LANZ AIRSHIP COMPANY.*

By Chief Engineer Gentzcke of the S-L Airship Company.

This article was prepared at the suggestion of the "Wissenschaftliche Gesellschaft für Luftfahrt" and is based on the experience of the Schütte-Lanz Airship Company in light construction. The object is to stimulate the employment of these methods in other fields of industry.

PART I - BUILDING MATERIALS.

A. Manner of employing materials.- The principal building materials are steel, duralumin and plywood. To obtain lightness, supporting structures are composed of open-work girders with diagonal braces. Plywood is suitable for girders and plates, but not for the diagonals. The latter are best made of strong steel wire, though duralumin and steel strips may also be used. By the crossing of two diagonal wires in a rectangular support, stiffening by means of a single rigid strut is avoided, with the advantages of smaller weight, simpler connections at the corners and great elasticity of the diagonal members. Fig. 1 is an inside view of the hull and walk-way of an airship.

* From "Zeitschrift für Flugtechnik und Motorluftschiffahrt," May 15, 1924, pp. 77-95.

Other views are given in "Zeitschrift für Flugtechnik und Motorluftschiffahrt," April 30, 1931. The hull is stiffened laterally by means of wires and struts attached at certain intervals to the transverse frames or rings. The individual girders composing these rings or (more accurately) polygons, the longitudinal girders and the unbraced intermediate rings dividing the distance between the braced main rings are built in the first place to withstand axial compression and tension and, in the second place, to withstand bending stresses. The walk-way in the lower part of the hull has a structure similar to the latter (which it serves to strengthen, as well as to transmit the load stresses to the main rings), with a triangular cross-section (Fig. 1). Its girders are likewise stressed both axially and transversely. The bending stresses on the girders are exerted on the junction points of the hull framework by the forces transmitted from the gas bags and loads.

The auxiliary parts are made of steel, duralumin, brass, copper, aluminum and German silver and are assembled, according to the principal material, by rivets of steel or duralumin and, for plywood, by hollow rivets of brass, aluminum or duralumin. Hollow steel rivets are used for uniting sheet steel or duralumin. Assembling parts are made of duralumin or sheet steel. Single form pieces, at junction points, are made of steel, duralumin or aluminium. Subordinate parts are also made of German silver.

B. Improvement of building materials.- Employment of the best materials is an essential condition for light construction. The original condition of the principal materials, steel, duralumin and wood, is capable of considerable improvement. The metals are made denser by rolling, drawing, hammering, etc., in the cold state. The texture of steel and duralumin is affected by thermal treatment. The thermal treatment consists in heating to a certain temperature, 750 to 900°C (1382 - 1652°F) for steel and about 500°C (932°F) for duralumin, and suddenly cooling in air, water or oil at different temperatures, with the difference that, for duralumin, the hardening first becomes evident about an hour after the cooling and continues to increase for 100 or more hours ("seasoning"), so that changes in shape can be conveniently effected immediately after the thermal treatment, e.g., the straightening of drawn profiled rods and the clinching of rivets. The brittleness produced by the hardening and subsequent working is remedied by a short period of heating, steel at 100-700°C (212-1292°F), duralumin at 100-150°C (212-302°F). The effects of the compression and tempering are partially or entirely destroyed by longer or shorter heating, steel 400-950°C (752-1742°F), duralumin 230-400°C (446-752°F), for which reason the thermal treatment must always take place before the cold compression. For most kinds of steel only one of the two processes can be employed. Steels containing chromium, nickel or wolfram have a greater hardness and strength, similar to duralumin with its constituents of copper, magnesium, manganese and silicon. The harder the metal, the less its ductility and pliability. Table E gives three examples for the above treatment, which produces the most widely differing properties (e.g., Table C). (For further information on light metals, see "Schiffbau," 1919-20, p. 556.)

It should, however, be borne in mind that the more difficult the treatment, especially with thin strips, the greater the tendency to irregularities and the greater care required. Use is made of metal sheets 0.5 to 5 mm (0.02 to 0.2 in.) thick, stamped pieces 1 to 5 mm (0.04 to 0.2 in.) thick, steel tubing with walls 0.3 to 1.5 mm (0.012 to 0.059 in.) thick, duralumin tubing with walls 0.5 to 2 mm (0.02 to 0.08 in.) thick and steel wire up to 4 mm (0.157 in.) diameter. In strips 1 mm (0.039 in.) thick and 4 m (13.12 ft.) long, there were found variations of 3.5% in strength and of 13% in thickness.

Wood has two disadvantages. First, the light rings are weak in comparison with the dark and split easily. Consequently, its tensile and compressive (Fig. 32, a-c) strength are relatively small crosswise of the grain. It is stronger perpendicular to the middle section (Fig. 34, a,b) than to the circumference. The reverse is true of the shearing strength. There are also irregularities of growth, crooked grain, accumulations of resin and rotten spots. In the second place, wood has a great capacity for absorbing and giving out water, causing it to swell and shrink (See "Hütte" 22, Edition I, pp. 720-721), so that, with irregular drying or wetting, it warps and buckles and, as a result of the stresses thus produced, it splits, especially in the weak zones. Moreover, the water absorption is synonymous with weight increase and strength decrease.

All these disadvantages are naturally aggravated by the thinness essential to light construction. They are remedied by careful selection of the wood and by two special methods, namely, by making into plywood and by impregnating or "doping." Plywood consists of layers of wood 0.5 to 2 mm (0.02 to 0.08 in.) thick glued together with the grains of adjacent layers at right angles (Fig. 33). These layers are cut circumferentially from the surface of peeled logs, as it were, by unwinding the natural layers or rings. Before the glue sets, the plywood can be pressed into any desired shape, which is permanently retained after the glue sets (Fig. 35). The crossing of the grains prevents splitting and causes a strong mutual support between the layers. The greater resistance, both to tension and compression, is in the longitudinal direction of the grain. By employing different woods, thicknesses, etc., different results are obtained in longitudinal and transverse strength and in durability. For example, some hard wood, like beech or ash, is used for the outside layer of a girder.

Doping retains the favorable properties of the plywood and, in addition to the above-mentioned advantages, serves to keep the glue dry. It accordingly consists of two processes, impregnating with paraffin and smoking with formaldehyde. The impregnation extends only to the surface pores and fibers. It does not fill the pores, but renders them water-tight. The successful results of this treatment are shown in Figs. 2-3. A good varnish alone affords protection against atmospheric moisture and prevents a weight increase of more than 4%. It also increases the strength of the surface layer (like the rolling of metals).

C. Workableness.- Strong sheet-metals with sufficient extensibility (steel 8-13%, duralumin 15% with bending radii of two to three times the thickness of the sheet) are best adapted from the strength standpoint (Figs. 4 and 22). The bending of the harder profile members and tubes requires a radius of at least 20 cm (nearly 8 in.). A malleable metal is necessary for making rivets, since the process of clinching increases their hardness. Moreover, in the case of duralumin, the hardening process is disturbed by such operations immediately after heating. Steel generally stands bending better than duralumin, as demonstrated, e.g., by the experiments with tubes according to Table F. Malleability data are obtained by bending tests (Fig. 31 c) and by depression tests (Fig. 31 b). The ratio of the breaking elongation D to the strength, according to Tables A and B, gives only one basis for judging.

In complex assemblies, parts made from a single piece of metal, forged and cast pieces, are employed for junction points, the first, however, being expensive and both of the others being relatively heavy, even after finishing. Moreover, only soft and medium steel, not less than 0.7 mm (0.028 in.) thick, and soft, but not sufficiently strong, aluminum are perfectly weldable and malleable, while duralumin, "Hartalumin" and German silver are not.

Strong steel wire (Tables A and B) is bent, for fastening, with a radius of two to three times its diameter, although with 30 to 50% loss in strength, which loss can be reduced, however, about one-half by winding and soldering.

Only steel is suitable for hard soldering, on account of its high tempering temperature, but not the light metals. Soft soldering is too unreliable, except for filling in between the windings in fastening wires.

Plywood cannot be changed much after the glue has set, except that the cross-section can be changed by gluing on pieces, which process corresponds somewhat to soldering and is a convenient means of adaptation to any desired shape.

Preparation with cutting tools (drills, revolving cutters, stamps) is the simplest and cheapest with plywood, the dearest with steel (cutting tools with diamond insct) and comparatively simple with the softer light metals. The hardness is determined by the ball pressure test according to Fig. 31a. Steel of $\sigma_z = 100$ can be drilled economically and can therefore be employed for the booms of riveted girders. The question as to whether still better steel can be successfully employed for soldering or welding is yet to be answered.

Heretofore metal girders, to be riveted, were made of the hardest metal that could be drilled or cut, while struts and braces, to be pressed or bent, were made of more flexible and consequently softer metal. This circumstance is taken into consideration in Tables A and B.

D. Strength relations.- The adoption of suitable materials is one of the chief problems in girder construction, since special designs are required not by the tensile and shearing strength (σ_z and τ), but by the resistance to buckling σ_k which decreases with increasing slenderness l/i and proceeds from the compressive strength σ_d as the limit. This principle applies both to individual profiled pieces subjected to bending stresses and to composite girders. In a girder assemblage, there is an increase in the buckling stress σ_{k_1} of the jointed member (measured between two supporting points) according to the strength of its joints, but, on the contrary, for determining the buckling stress σ_{k_0} of the whole girder, there is a decrese, according to the slenderness, design, and method of fastening, which, in a simple manner, express the Tetmajer-Krohn relations, namely,

$$\sigma_{k_0} = \sigma_{k_1} B C = \left(a - b \frac{l}{i} r_1\right) \left(1 - \frac{b}{a} \frac{L_0}{i_0} r_2\right) C.$$

in which l represents the length; i, the inertia radius of the individual flange; L_0 and i_0, the same for the girder; a and b, building material constants; r_1 and r_2, factors which express the fastening method of the individual member and girder as a length reduction. On ordinary girders of about 5 m (16.4 ft.) length, r_1 varies between 0.75 and 0.90 and the quantity B C between 0.5 and 0.7. The equation applies to two compressed flanges in bent girders. The minimum value (in any possible buckling direction) must always be used for i_0.

By way of illustration, Fig. 6 shows the relations of the above equation for a girder made of angular sheet duralumin. It also shows the effect of the flange height and thickness. Fig. 7 gives the buckling curves of different materials and shapes for single members, and Tables A, B, G, H give their moduli of resistance. Flexibility is assumed for metal sheets and capability of being cut or drilled is assumed for the steel profiles of Table B for structural data.

While the modulus of resistance varies but little for any given metal, it fluctuates greatly for one and the same kind of wood due to the peculiarities of growth. Table G contains data for good soft and hard wood. The compressive resistance is greater than that usually given, as repeatedly shown in Table H under σ_W, and is manifested in bending tests as the bending strength σ_b. With plywood, however, contrary to the case with ordinary wood, this strength is fully utilized, even in the case of pressure stresses, due to the mutual support of the grains. This explains the fact that plywood, notwithstanding the reduction in cross-section through cross-veneering, has approximately the same compressive resistance as ordinary wood. The values σ_w in Table H have to be somewhat increased as σ_d for plywood; for example, with three equally strong aspen-wood layers, to about $2/3\ \sigma_b = 2/3\ (550 \simeq 360)$ kg cm², when σ_z becomes $2/3\ (800 \simeq 530)$. Fig. 8 shows the buckling loads of ordinary and plywood spars of like length and weight. In airship construction, aspen wood is preferred on account of its homogeneity, small water absorption and relatively small specific gravity. The data for this wood are comparable with those for duralumin and steel in Table B and compare with sheet duralumin in the ratio of 1 : 7.5 up to 1 : 9.

The elasticity limit of plywood is indefinite and difficultly determinable. It may be assumed to be above 0.7 σ_d, a value exceeded by steel and duralumin and corresponding to a structural safety factor of about 1.5. Nevertheless, small permament distortions remain in wood after unloading. Its elongation is considerably greater than that of metals. For example, according to Fig. 23 E, a girder 2.28 m (7.48 ft.) long, on being subjected to four separate loads equal to 2/3 of the breaking load, underwent an elastic depression of 77 mm (3.03 in.). The stretching and crushing limits do not generally lie much beyond the limits of elasticity and are higher for metals, in proportion to their hardness. For hard metals and plywood, they are hardly determinable, since they almost coincide with the breaking limits. Girders of such material, especially of plywood, collapse suddenly without previous warning.

No noteworthy difference was observed between steel, duralumin and plywood in the fatigue produced by stresses 10 to 15% below their limits of elasticity, or 0.6 of their breaking strength. In the event of over-stressing rods of like static strength, medium steel is superior to the other materials (Table F). Dry wood does not behave so well as duralumin. Endurance tests can be made under conditions nearest approaching the actual, e.g., according to Figs. 29-30.

Strength relations are made worse by external mechanical influences, like flaws in the surface of rolled metals or in the outer layer of plywood, and by the chemical action of air and moisture. Steel oxidizes strongly and the corroded layer is not permanent. German silver also oxidizes strongly, and in a finely divided form, burns freely in the presence of moisture and in contact with an open fire. Aluminum and duralumin oxidize slowly in the air, are not at all affected by pure water and only slightly by sea water and the oxidized layer is permanent. Hence steel and German silver should be protected by varnishing, painting or plating, while such treatment is not absolutely necessary for aluminum and duralumin. Wood can be protected from water by impregnation and painting.

E. Weight and quality.- Lightness of construction can be attained by adapting the materials to the required forces. The materials are judged by their quality, which is determined from the ratio of a load and weight unit. The quality of the material is $G_m = \sigma_z : \gamma$ or $\sigma_d : \gamma$ = strength divided by specific gravity and indicates what strength is attainable with a specific gravity of 1 (Tables D and J). The quality of a rod is represented by $G_s = \sigma_k : \gamma$ = resistance to buckling divided by specific gravity and takes into account the effect of the length on the resistance to buckling. It is especially important and is represented by curves in Fig. 9 for a number of different materials. The insufficiency of $G_m = \sigma_d : \gamma$ is demonstrated by the different courses of these curves. Thus it appears, according to G_m, that steel and duralumin have the same value and that plywood has hardly half the value, while, according to G_s, the quality of steel and plywood improves with increasing length, as indicated by the small inclination of their curves. For example, the quality G_s of a plywood spar of cross-section $f = 1.7\ cm^2$ is just as good as that of a sheet duralumin spar of like weight and of more favorable form of cross-section $f = 0.34\ cm^2$, as soon as the common length of 24 cm (9.4 in.) is reached. Beyond this length, the plywood cross-section is superior. A medium steel tube 30/1 of $\sigma_z = 65$, with a length of $l = 73$ cm (28.7 in.) has the same value as a similar steel tube of $\sigma_z = 100$, length $l = 26$ cm (10.24 in.), and as a like tube of duralumin. Nevertheless, for the steel tube, the buckling load is in proportion to the specific gravity, i.e., about 2.8 times greater than for duralumin, according to which its thickness can be reduced to 1/2.8 = 0.36 mm (0.014 in.), i and σ_k remaining approximately equal, since i varies as 1/3 of the diameter. Such thin-walled tubes can be made (Table C). A similar reduction for the above plywood and duralumin spar brings us to the insufficient thickness of only about 0.3 mm (0.012 in.). This demonstrates the superiority of plywood for small stresses, since any necessary increase in the reduced thickness is synonymous with an increase in the stress.

The curves show further that tubes are better for long members, but that open profiles can be used for short members. The effect of the cross-sectional shape is seen by comparing duralumin profiles and tubular cross-sections of like area, 1.74 cm² (.27 sq.in.) (Fig. 9).

Two rods of different lengths l_1 and l_2, but of the same quality G_S, may be brought to the length l_2 by a similar increase of the shorter one (whereby l/i, σ_k and G_S remain constant) by multiplying its cross-section f_1 (or buckling load) by $(l_2/l_1)^2$.

This calculation shows how great its buckling load (or force to be withstood) of a shorter rod becomes, which is given the greater length of another rod used for comparison, with the retention of constant quality. If the buckling load P_{k_2} is given and if the rod under consideration has a cross-section f, a length l_1, and a buckling load P_{k_1}, we can then make this equal to P_{k_2}, with retention of constant quality, by changing its cross-section and length in

$$f_x = f_1 \frac{P_{k_2}}{P_{k_1}} \quad \text{or} \quad l_x = l_1 \sqrt{\frac{P_{k_2}}{P_{k_1}}} \quad -$$

By means of these expressions, the curve values can be compared in different directions.

The quality only enables us to reach a satisfactory conclusion, when we know the type of girder, of which the given rod is a member. The type of girder depends largely, however, on the kind and quality of the material. Hence, construction qualities are established, namely, G_k = breaking strength divided by the weight per unit length, e.g., of a running meter (eventually also = breaking moment divided by weight). We must also find the most favorable dimensions of the strut divisions t and of the flange and strut cross-sections for given lengths and heights, kind and magnitude of loading, i.e., the smallest possible volume of building material for the purpose. This was, e.g., done in Fig. 10, for tubular girders, in which certain cross-sectional dimensions are not exceeded. Here the best division number is 13 (for 5 m length, thus making the length of a single division 38.5 cm (15.16 in.). This process is repeated for different heights. We thus attain our goal more easily than by employing equations which can show no continuity. The qualities of girders are given in Tables K, L, M and N, which will be discussed later. In comparing the qualities of two different girders, it is assumed that their cross-sections remain the same for the same length, L_2 being the greater and l_1 the lesser length. The new quality of the shortened girder becomes, e.g., $G_X = G_2 \, B_X : B_2$, in which B is taken from the buckling formula in the preceding chapter and $L_X = L_1$. We write approximately $b : a = 1 : 100$ for duralumin and $1 : 200$ for plywood and $r_2 = 1$. For girders with two compressed flanges subjected to bending stresses, we have approximately $G_X = G_2 \, (B_X/B_2) \, (L_2/L_1)$ and for those with one compressed flange we have $G_X = G_2 \, (L_2/L_1)$.

Any comparison according to quality is naturally of value, only when the differences are not too great in the meter weights or buckling loads of the girders constructed for comparing one of these quantities. When the differences are too great, the girder appears too favorable with the greater weight or greater buckling load, because not only the cross-section but also the σ_k increases with increasing weight and, moreover, the ratio of the weight of the flange to the weight of the struts undergoes a change. Thus, e.g., two girders, whose weights per meter and whose buckling loads are each in the ratio of $1 : 2$, are not directly comparable in the above sense, but are, however, when the values of the one kind differ from one another only by 10 to 30% and the values of the other kind are optional. It should be remarked that the given degrees of excellence present no exceptional values.

Table A. Strength and Elongation of Metals.
(σ in kg/mm²)

		Steel			
		Sheet	Profile	Tubing	Wire
Breaking strength	σ_z	< 90	< 130	< 160	< 220
Yield point	σ_{str}	< 60	< 110	< 120	< 160
Crushing strength	σ_d	< 80	< 130	< 160	--
Elongation	D	20-10	20-5	12-5	2-6
Shearing strength	τ		72-130		
Elasticity limit	σ_e		0.4-0.8 σ_z		
Modulus of elasticity	E		~ 22000		

		Duralumin		
		Sheet	Profile	Tubing
Breaking strength	σ_z	30-45	32-50	52-55
Yield point	σ_{str}	24-33	24-37	24-43
Crushing strength	σ_d	30-43	30-43	33-50
Elongation	D	23-10	18-8	16-2
Shearing strength	τ		24-37	
Elasticity limit	σ_e		24-36	
Modulus of elasticity	E		~ 7000 ÷ 7500	

		Aluminum		German silver
		Cast	Hard	Profile Weight
Breaking strength	σ_z	< 11	< 45	> 30
Yield point	σ_{str}	--	--	~ 19
Crushing strength	σ_d	< 11	< 33	< 35
Elongation	D	> 9	> 3	> 3
Shearing strength	τ	--	--	--
Elasticity limit	σ_e	--	--	--
Modulus of elasticity	E	~ 6750	--	~ 4500

Table B. Structural Data.

	Steel				Duralumin		
	Sheet	Profile	Tubing	Wire	Sheet	Profile	Tubing
σ_z	80	100	100	160	40	42	45
σ_{str}	50	75	75	140	33	33	34
σ_d	70	100	100	--	33	38	40
D	15	10	10	3	15	10	8
τ Rivets		50				24	

Table C. Illustrations.

I. Steel.

	Breaking strength σ_z*	Yield point σ_{str}	Elongation D
Air-hardened tubing 40/03 mm	160	--	3
Not hardened " " "	100	--	12
" " " " "	64	--	4
Steel band, thickness 0.3-0.5 "	130	120	5
U-profile	80	50	12
"Structural steel"	85	73	15
	120	90	10
	105	80	13

II. Duralumin.

	σ_z	σ_d	D
Tubing 30/1 mm	46	38	12
" 30/1,25 mm	46	43	5
U-profile	47	35	22
" "	40	38	12

* Differs but little from σ_d.

Table D. Specific Gravity and Quality.
G_m (in cm.)

	Specific gravity	Quality of material according to maximum values of Table A. $G_1 = \sigma_Z : \gamma$	$G_2 = \sigma_d : \gamma$
Steel, sheet	--	1150	1000
" profile and tubing	~ 7.85	1600/2000	1600/2000
" wire	--	2500	--
Duralumin, sheet	--	1600	1500
" profile	~ 2.8	1800	1600
" tubing		2000	1800
Aluminum, cast	2.65	400	400
Hard aluminum, profile	2.7	1700	1200
German silver	1.8	1600	1900
Plywood (aspen)	0.6	--	--
Supporting cross-section about 70%	0.5	--	--

G = quality.

σ_Z = breaking strength in kg/cm²

σ_d = compressive strength.

γ = specific gravity.

Table D. Specific Gravity and Quality (Continued).
G_m (in cm.)

	Specific gravity	Quality of material According to Tables B and H. $G_1 = \sigma_z : \gamma$	$G_2 = \sigma_d : \gamma$
Steel, sheet	--	1000	900
" profile and tubing	~7.85	1300	1300
" wire		2000	--
Duralumin, sheet	--	1400	1200
" profile	~2.8	1500	1300
" tubing	--	1600	1400
Aluminum, cast	2.65	--	--
Hard aluminum, profile	2.7	--	--
German silver	1.8	--	--
Plywood (aspen)	0.6	870	600
Supporting cross-section about 70%	0.5	1050	700

G = quality.

σ_z = breaking strength in kg/cm².

σ_d = compressive strength.

γ = specific gravity.

Table E. Examples of Improvement of Metals.

I. Duralumin sheet-rolled and tempered:		
1. Sample heated to 350°C, cooled in water at 100° and immediately tested,	σ_z = 33	D = 15%
2. Sample heated to 500°, otherwise as above,	σ_z = 23	
3. Sample heated to 500°, cooled in water at 20° and tested after 6 days,	σ_z = 48.5	D = 21%
4. Sample heated to 460°, cooled in water at 20° and tested after 4 days,	σ_z = 45	D = 22%
Ditto - cooled in air.	σ_z = 44	D = 21%
II. Duralumin sheet heated to 400°:	σ_z = 27	D = 17%
1. Sample rolled cold,	σ_z = 36	D = 2%
2. Sample tempered at 500°, tested after 4 days,	σ_z = 42	D = 22%
then rolled cold,	σ_z = 53	D = 3%
then heated to 400°;	σ_z = 26	D = 16%
same as before, only instead of heating, the metal was re-tempered at 500°.	σ_z = 41	D = 20%
III. Chrome-nickel-steel sheet:		
1. As delivered;	σ_z = 79	D = 13%
2. After heat tempering;	σ_z =160	D = 2%
3. After reheating to 350°.	σ_z =159	D = 6%

Table F. Bending Tests with Strips 2 cm Wide Cut from Tubes.

	Angle	Fig. 31c	No. of bends	Remarks
1. Steel tubing 30/1 mm	30°	I	27	$\sigma_d = 60$, $\sigma_z = 65$; D = 8%
	45°		22	
	30°	II	12	
	45°		10	
2. Duralumin tubing 30/1.25 mm Variety A	30°	I	2	$\sigma_d = 44$, $\sigma_z = 51$; D = 5%
	45°		1.5	
	30°	II	1.5	
	45°		1	
3. Duralumin tubing 30/1 Variety B	30°	I	6	$\sigma_d = 38$, $\sigma_z = 49$; D = 13%
	45°		3.5	
	30°	II	3.5	
	45°		3	

Table G. Strength Coefficient in kg/cm³ for Good Wood.

For the softer woods (pine, aspen), the smaller numbers apply. For the harder woods (ash, beech, locust), the larger numbers apply.

Parallel to the grain, $\sigma_d = 360 - 750 \text{ kg/cm}^2$

$\sigma_z = 1.2 - 1.5\ \sigma_d$

$\tau = 1/8 - 1/6\ \sigma_d$

Crosswise of grain, $\sigma_d' = 1/10 - 1.4\ \sigma_d$

$\tau' = 0.3 - 0.5\ \sigma_d$

Table H. Mean Strengths in kg/cm² with 15-20% Moisture Content (15% = air-dried).

Kind of strength		To the grain	Oak	Beech	Ash	Elm	Tallow
Tensile	σ_z	=	1000	1300	1300	1000	1100
Compressive	σ_w*	=	360	300	500	400	630
Shearing	τ	=	80	80	60	60	100
Bending	σ_b**	=	600	670	850	850	1000

Kind of strength		To the grain	Larch	Pine	Spruce	Fir	Aspen
Tensile	σ_z	=	1100	800	750	800	800
Compressive	σ_w*	=	450	280	270	300	320
Shearing	τ	=	70	40-60	40-70	60	50
Bending	σ_b**	=	600	420	430	550	550

= means parallel to the grain.

*σ_w = cube strength < σ_d.

**σ_b = compressive strength with support of the grain, which is essential for plywood.

Table I. Specific Gravity of Wood and Quality of Material G_m.
(The bracketed numbers apply to plywood.)

	Specific Gravity*			Quality	
	Air-dried 10% moisture mean value γ_1	kiln-dried at 110°C mean value γ_2	$\gamma_1 - \gamma_2$	G_m in cm $= \sigma_z/\gamma_1$ 10% moisture	G_m in cm $= \sigma_d/\gamma_1$ 10% moisture
Maple	0.67	0.63	--	--	--
Birch	0.64	0.61	--	--	--
Oak	0.86	0.66	0.20	1160	420
Alder	0.53	0.43	--	--	--
Ash	0.75	0.62	0.13	1740	670 (725)
Spruce	0.47	0.44	0.03	1600 (1050)	530 (600)
Pine	0.52	0.51	0.01	1540 (1000)	560 (530)
Larch	0.62	0.46	0.16	1780 (1150)	725 (630)
Linden	0.46	0.42	--	--	--
Poplar	0.45	0.37	--	--	--
Aspen	0.48	0.40	0.08	1670 (1100)	625 (725)
Pitch pine	0.70	--	--	--	--
Beech	0.74	0.57	--	--	--
Elm	0.69	0.52	0.17	1450	580
Hornbeam	0.72	--	--	1800	420
Fir, silver	0.48	--	--	1670	621

* The specific gravity and compressive strength are greater for plywood than for ordinary wood.

PART II - METAL CONSTRUCTION.

A. Girders.- The following experiments were made with duralumin girders, but the results hold good, in principle, for girders made of steel or other metals.

1. Plain girders (Fig. 37).- For considerations of weight, these can be employed only in relatively small lengths. For greater lengths, the consumption of material would be much too great. We have the following kinds (Fig. 37):

1. Open and rolled (row I);

2. The same hot-pressed in the case when the cross-section changes with the length of the girder (e.g., transition from g to c in row I);

3. Open and hot-drawn profiles (rows I and II);

4. Closed and hot-drawn profiles (row III);

5. Shaped cold out of sheet metal (rows I and II);

6. Cold-rolled from sheet metal (row I);

7. Cold-pressed from sheet metal (row I);

8. Open profiles cold-drawn from sheet metal (rows I and II).

Girders made by the hot process have to be reheated and hardened. Girders made from tempered and rolled sheet metal are still further hardened by the shaping process and are therefore to be preferred. Small sheet-metal parts are shaped by simply bending and pressing (Fig. 22). Closed profiles may be made from sheet metal, by riveting, welding or soldering. Hot or cold rolling and pressing cannot be employed for tubes and open profiles with converging edges (row II). These must be drawn.

Hence row I contains open profiles, which can be either drawn, bent, or pressed; row II, open profiles which can be cold-drawn or bent; row III, only closed profiles, which must be drawn; row IV, profiles which can be made by riveting other profiles together. In addition to the examples shown, a number of intermediate steps are possible. The converging edges of the profiles in row II are proof against buckling, only when braced at certain intervals with respect to each other.

For greater cross-sectional dimensions, the plain girders would have to be made of quite thick metal, in order to be secure against buckling, especially for open profiles. In any case, it would be possible to use thin-walled tubes of large diameter (e.g. 20 cm (7.87 in.) with transverse bracing partitions or bulkheads, an arrangement employed by nature in bamboo. Even in this case, however, it is advisable to strengthen the cross-section by riveted bands or by corrugating and to provide the walls of the tubes with crimped perforations.

On the other hand, the accumulation of the material about a few suitable axes uses the material to much better advantage, if the individual members are well stiffened. This can be accomplished: first, by the union of perforated metal sheets; secondly, by the union of the girders with sheet-metal bands; thirdly, by the union of the individual members by means of struts. The structural parts thus obtained are considered in the following section.

2. Open-work girders made from stamped sheet metal.- These can be made either by stamping the plain profiles of Fig. 37, or by stamping sheet metal with subsequent shaping and mutual bracing. The latter is the more common method. The basic form of a girder wall is shown in Fig. 38. The stamping of the walls offers the very great advantage, that the stamped holes can be simultaneously provided with a crimped flange c. This means the choice of a flanged angle as the flange a and of a U-section as the web b, two shapes which mutually support each other. On account of their greater hardness, the stamped, high-grade tubes cannot be flanged. Thus are obtained the following cross-sections of Fig. 43, namely, the stamped unflanged oval or rectangular cross-sections 1-3. The strength is relatively small, on account of the lack of crimping and the faulty support of the longitudinal members. The perforated oval tube has advantages when stressed in its longitudinal axis, but a rectangular cross-section better withstands bending stresses.

The remaining figures (4-15) show parts stamped out of sheet metal. No. 4 is not very rigid and is important only when riveted together in the double form of No. 5 (T-section). Nos. 7 and 8 are bent out of one piece and riveted together by overlapping (on the plan of Fig. 41a). Nos. 6 and 9 are made of two pieces; Nos. 10-11, of four pieces; No. 12, of a U-section riveted to a connecting strip (16). The box-shapes 6-7 and 9-12 must be made of relatively thick metal in the larger sizes, in order to prevent the cross-sections from becoming oblique-angled, a disadvantage to which No. 8 is not subject. This tendency may be overcome by adopting the arrangement of Fig. 13, in which the angular flanges completely overlap. The strength of the combined flanges is then large, but that of the webs is small. The crimping occasions less difficulty and the right ratio of the flange and web strengths can be approximated. More riveting is required, but this is not important, except when done by hand. Another method of stiffening is shown by No. 15, through the introduction of diagonal partitions, which considerably increase the weight. No. 6 is a two-part cross-section with holes in only two planes. It is composed of two No. 4 sections, is wider than high and therefore requires a narrower support in the vertical than in the horizontal position. All these girders with triangular and rectangular cross-sections are suitable for compression struts. Their webs can be small, on account of the small shearing stresses. When subjected to bending stresses, they undergo considerable distortion and require stronger webs, in order to withstand the greater moments and shearing stresses.

Such a girder is therefore very yielding and suffers great elastic deflections, even under small bending loads, a behavior which is very desirable under certain conditions. When this is not the case and the shearing stresses are too great, the sheets must be stamped in the form of crossed webs with crimped edges (Fig. 40). This type offers more resistance to buckling. All girders made of stamped sheets have the disadvantage of wasting more material.

3. Open-web girders made from longitudinal and transverse members.- This type avoids the great material waste of the preceding type (Figs. 39 and 44). It also has the advantage that the longitudinal members can be made of hard-rolled or drawn metal, while the transverse members can be made of pliable sheet metal of less thickness and rigidity. The transverse members are formed out of sheet metal, as rigid frames, transverse walls, or simple connecting strips. The rigid frame consists either of a U-shaped relatively wide sheet riveted together at one place (Fig. 44, Nos. 1-2, and Fig. 42g) or of an angular sheet (Fig. 44, No. 3), of which one arm is interrupted at the corners and riveted to the other by overlapping after bending. The transverse walls in Fig. 44, No. 4, are made like Fig. 43, No. 4, or, better, like No. 5. The separation of the cross bracing into the individual connecting strips is shown in Fig. 44, Nos. 5-8. The frames in No. 1 (Fig. 11) are very light and efficacious in producing a greater longitudinal and lateral rigidity, as illustrated by Fig. 42. The distortion of the girder is considerable, however, especially for greater lengths and greater transverse stresses. With sufficient width, the open-work and crimping of the free frame walls produce a diminution in weight and an increase in the rigidity. The frame like Fig. 44, No. 3, is much more efficacious with a U-shaped than with an angular cross-section. The cross wall like No. 4 is especially suitable for points where there are great shearing stresses (e.g., at joints) and requires more weight.

If the bracing consists of simple strips of sheet metal, like Fig. 44, Nos. 5-8, and Fig. 12, then, for obtaining sufficient lateral rigidity, the longitudinal members must themselves be rigid and the flanges of the lattice strips must extend to the flanges of the longitudinal strips. Fig. 41 b represents such a perforated and crimped lattice strip. For small sizes, the perforating does not pay (Fig. 44, Nos. 7-8). If the longitudinal members are tubes, then Nos. 9-10 are employed as modifications of Nos. 1-2. The modifications of No. 3 are Nos. 11-12, in which the corners are stiffened by special brackets or flanges. The modifications of No. 4 are Nos. 14-15 and the modification of Nos. 5-6 is No. 13.

Curve tables, after the manner of Fig. 6, are employed in designing the girders considered in this and the preceding chapter. On the right-hand side there is a set of curves for the center-of-gravity stresses of the girder σ_{ko} plotted against the ratio $L_o : i_o$ and the stresses σ_{k_1} of the simple longitudinal girder member. The σ_{k_1} stresses are obtained from the left-hand set of curves, under consideration of the most favorable values for $H : d$ and $l : d$, as given by the enveloping curve. For a given σ_{ko} we can choose $L_o : i_o$ and find, over σ_{k_1}, the most favorable $H : d$ and $l : d$, naturally under consideration of the formation previously mentioned. For square girders (with two-way rigidity), under consideration of Figs. 38-39, the section t is about 1.1-1.5 H. For rectangular girders (one-way rigidity), it increases to 2.5 H (e.g. Fig. 44, Nos. 7-8).

The weight of the transverse members is, according to the lateral stress, 25 to 40% of the total weight. In compression struts (Fig. 4), the thickness of the metal of the transverse members is about one-third that of the longitudinal members.

All of the above-mentioned girders, with side walls formed by rectangular frames, are poorly adapted for the transmission of great lateral stresses and for greater lengths than 3-5 meters (9.84-16.4 feet). Thus, e.g., the sheet duralumin girder of Fig. 11 has, according to Table K 2 and 2a, for a length of 1.2 m (3.94 ft.), a height of 7 cm (2.75 in.), and a thickness of the longitudinal members of 1.5 mm (0.06 in.), a buckling load of 4000 kg (8818 lb.), corresponding to $\sigma_{ko} = 24$ and a relatively high efficiency $G_k = P_k \div$ weight of 1 linear meter = $4000 \div 0.77 = 5200$. On increasing the linear dimensions 3.5-fold, we obtain a length of 4.25 m (13.94 ft.) and a height of 25 cm (9.84 in.), as may normally occur in airship construction. Under retention of the same favorable ratios $L_o : i_o$, $l : d$, $H : d$ (Fig. 6), σ_{ko} remains about the same and the buckling load increases to $4000 \times 3.55 \times 3.55 = 52000$ kg (114640 lb.), whereby the efficiency remains 5200 (Table K2, 2a), while, e.g., we can obtain, with the strut girder 7, about the same efficiency with the much smaller breaking load of 9000 kg (19842 lb.) and with the same length. For such small buckling loads, a latticed sheet-metal girder would therefore have more unfavorable ratios $l : d$ and $H : d$, or a greater weight of the transverse members, since the latter would have to be placed at very short intervals.

4. Lattice girders.- The longer girders are almost exclusively of this type, consisting of from two to four longitudinal members connected by transverse or diagonal lattice bars or struts (For cross-sections, see Figs. 46-47). Thus we have an intermediate type between that considered in the preceding chapter and the theoretical triangular braced girder. The struts are accordingly subjected to moments in the transverse and especially in the longitudinal direction in addition to the axial stresses. The eccentric connection has only an insignificant and not detrimental effect on the strength of the flanges (longitudinal members). Girders with two and more flanges will be considered.

a) Two flange girders.- These are employed when, in the plane of their least resistance, there is the possibility of firm supports at frequent intervals (Figs. 45a and 45b) by bracing with the junction points of other girders. On account of the narrowness of the girders, the torsional rigidity must be principally supplied by the struts. This could only be accomplished by making the latter very heavy or by frequent lateral bracing, which, in practice, is seldom possible. Hence such girders, with intervals between the braces of, e.g., four to ten times the girder height, are not especially suitable. The cross-sections shown in Figs. 37, 43 and 44, are employed, with few exceptions (Fig. 46) as flange and strut sections. The struts are best made according to Fig. 44, Nos. 7-8, and Fig. 12, b-d, whereby the end portion of each strut, due to the unfavorable location of the buckling line, must be equal to or smaller than half the middle portion and must be stiffened by a connecting gusset on the flange (46 b). The incomplete composite profiles 14 and 16 in Fig. 43, serve as flanges of smaller dimensions, as likewise do Nos. 7-8 of Fig. 44 (corresponding to a and b of Fig. 46). For larger dimensions, the whole composite cross-sections serve as flanges, according to Fig. 43, Nos. 7, 9-13 and 15, and Fig. 44, Nos. 1, 5 and 6 (corresponding to 46 d) as also the plain-girder cross-sections, Fig. 37, p-r and u-y. Of the latter, the oval or rectangular tubes, corresponding to Fig. 46, c and e, are the best. Since the distribution of the bracing is generally greater than that of the struts, the flangs cross-sections must be shaped on a large and on a small axis, whereby the former comes to lie in the direction of the lateral bracing. The same principle obtains as regards the struts, for reasons of lateral rigidity.

By way of comparison, the qualities of the 1.2 m (3.94 ft.) girder (Fig. 46, c and d) with struts of like kind and weight and flanges of like weight and distribution are considered. The rectangular girder (Fig. 11) weighs 770 g/m (with cross-bracings) and has a $\sigma_{ko} = 24$, $P_k = 4000$, $F = 1.68$ cm². The oval duralumin tube, which, likewise, weighs about 770 g/m and is made from a tube 60 × 1.5 mm (2.36 × 0.06 in.), has a $\sigma_{ko} = 27$ at the breaking point, an $F = 2.75$ cm² and breaking load $P_k = 7400$ kg (16314 lb.). If we assume the weight of the struts per running meter to be 0.33 of the weight of the flanges, i.e., 0.33 (2 × 0.77) kg = 0.51 kg/m (about), then the quality of the girders $G_k = \frac{4000}{1.54 + 0.51} = 1950$ and $\frac{7400}{1.54 + 0.51} = 3620$. The quality of the girders is therefore about 1.85. This ratio decreases for smaller flange cross-sections. The ratio of the strut weight to the total weight of the girder is 1 : 5 to 1 : 3, according to the transverse force and manner of bracing.

Such girders require a lot of rivet and stamp work. Instead of riveted struts, simple stamped pieces (Fig. 43, No. 4) or perforated tubes (Fig. 43, Nos. 1-3 and Fig. 46, f) can be used. The stamped pieces are too soft, but the perforated tubes can be successfully used only in the case of very great shearing forces and abnormally long struts.

b) Three and four flange girders.- Three-flange girders have, because of their nearly triangular cross-section, great transverse rigidity and, for approximately equal cross-sectional angles (60°), very great torsional rigidity. Fig. 47, a to e, and Figs. 13-16, are cross-sectional forms showing the position of the struts. Fig. 48, a to e, shows diagrammatically the various strut arrangements whereby the side walls must be imagined as turned down into the plane of the drawing, so that the flange axis appears twice. Arrangement a is the transitional form to the girders with connecting plates or lattices of sheet-metal and can be used only when the shearing forces are small in the wall where these plates are (Fig. 4, e). Arrangement b of Fig. 48 has, in addition to the struts s, also the posts p for producing the triangular transverse frames 4, 5, 6, 4, for the purpose of greater transverse rigidity, as required, e.g., where there are bending stresses in two directions. Arrangement c (Fig. 48) does not have the closed triangle. Hence, the rigidity of the cross-section 7, 8, 10, 7, is dependent on the rigidity of flange II at 9 and is, in general, probably sufficient to prevent buckling, but not bending. Instead of the posts and struts in the one wall in arrangement b, we can provide strut crosses according to arrangement d (Fig. 48) with the same or a smaller weight in the same plane between flanges II and III, whereby closed transverse triangles are also formed, namely, 11, 12, 13, 11. (For strut-crosses see Fig. 4a.) Arrangement e has such crosses throughout, by which the free length of each strut and flange is halved and their resistance to buckling increased. This result is very desirable in open profile flanges and greatly increases the utility of girders employing them. For tubular struts (Fig. 4b) and flanges, the advantage of the crosses is not so pronounced.

For flanges, the best profiles are Fig. 37 e, i, k, m, n, o, p, s, t, z; for struts, Fig. 37g, p, q, r (simple struts) and Fig. 44, Nos. 6, 7, 8 (composite struts). The double U-struts are especially suitable for use with tubular flanges (Fig. 49) and afford great rigidity in consequence of being connected in two planes.

The stamped sheet-metal struts (Fig. 37 g) are very easily made, are the best kind for use with open-profile flanges, and can also be used with tubular flanges. The corrugated cross-section in the middle of the strut (Fig. 4c) changes gradually toward the ends into a flanged surface, whereby the resistance to buckling and the strength of the joint are both increased.

These struts can be very easily crossed and riveted together (Fig. 4a). One strut is riveted to the inside and the other to the outside of an open profile flange, with the advantage of better conserving the straight line of the axis of gravity and using the same strut for both arms of the cross, neither of which would be possible with a one-sided connection (Fig. 13). This method is preferred (e.g.) by the Zeppelin Company. The broad flat form of the strut arm affords a greater resistance to buckling and bending in the longitudinal direction of the girder and a smaller resistance in the transverse direction, that is, it is adapted to the reception of greater additional moments in the planes of the side walls and accordingly increases the longitudinal rigidity of the girder. The chief advantage of crossing two flat struts is their mutual support in the transverse direction, in which their rigidity is small.

Tubular struts are best suited for use with tubular flanges, since both, because of their great inherent rigidity, enable greater free lengths and require less bracing. Tubular girders are preferred by the Schütte-Lanz Company. The connections of the tubular struts are enabled by flattening their ends after they have been reheated. In short struts, the weakening produced by the flattening is offset with the aid of short tubes inserted in the ends of the struts before flattening. Tubular strut-crosses can be made by interrupting one strut and fitting the ends to the sides of the other strut or by the use of cross-shaped clamps (Fig. 4b) or cross-shaped inserted pieces. The use of tubular crosses is advantageous only in case of large shearing stresses (Fig. 15). It is best for the flattened ends of the struts to fit the flanges closely, in order to prevent any turning of the strut about the junction line of the two fastening rivets. For this purpose, however, the strut must have sufficient transverse rigidity.

Sometimes it is desirable for the struts not to project beyond the plane of the outer walls of the flanges. This can be easily accomplished according to Fig. 14b and Fig. 47c,e and necessitates a shifting of the struts or strut-crosses in the longitudinal direction, as shown in Fig. 49. Any shifting, however, should be made in such manner as to weaken the flanges the least possible by riveting. In such an arrangement, the three struts in the same transverse section of the girder can be united into a single body, thus simplifying the construction and considerably strengthening the girder.

The triangular girders are made rigid enough in the transverse direction by their shape, have three supporting planes and are therefore the best to resist buckling stresses. On the contrary, the shearing forces, acting at right angles to a plane of symmetry of the girder, must be transmitted in a single side wall and the eccentric junction of the struts in this wall (due to the distance from the flange axis) produces unpleasant effects when subjected to great shearing forces. Four-flange girders are better in such a case. It is sometimes better also for structural reasons. Such a girder requires a special system of transverse bracing which, most suitably for the production of a continuous triangular assemblage, lies in the transverse planes formed by the side-wall struts. Figs. 50a and 50b show the side-wall struts with and without crossing. The line 1-4-1, formed by the struts, lies in an oblique transverse plane, which is shown in Fig. 52a, and 52b. The struts, which fall in these planes, form a continuous bracing system. For many purposes, it is only necessary to place the struts at right angles to the longitudinal axis, whereby the strut crosses are best made of tubes, on account of the different location of the junction plane. Figs. 51 and 52c show the case where the side and transverse struts combine to form oblique transverse partitions. The lines 1, 2, 3, 4, 1, indicate the outline of such a partition. When the shearing force parallel to the walls I-II and III-IV is small, the arrangement 51a suffices, but when the shearing force is great, struts or strut-crosses must be introduced into these walls according to Fig. 51b. A transverse partition or box can naturally be substituted for a transverse strut, the former being preferable where the stresses are great.

As already mentioned, the strength of the flanges is more or less dependent on the nature of the bracing. Both are mutually related, as also expressed in their weights. The closer the struts, the more they weigh and, within certain limits, the lighter the flanges can be. Great rigidity of the struts and their connections has the same effect on the flanges.

The following table gives the percentage weights of the struts, as compared with the weights of the complete girders.

		Simple struts	Strut crosses
Three-flange girder:	Compression	19-25%	28-35%
	Bending	19-30%	28-44%
Four-flange girder:	Compression	22-30%	32-40%
	Bending	22-35%	32-49%

The quality of the girders may be learned from Tables K and L. As was to be expected from the foregoing, the tubular girders occupy the first place. The best girder dimensions, for a given load, length and height, can be approximately determined from Fig. 10, which holds good for tubular girders (See above). For closed profiles, the spacing varies between 1.5 and 2 times the height. For open profiles, the divisions would be about half as large. For determining the dimensions, curve diagrams are used, which plot the buckling loads against the various division lengths for every kind and size of profile.

From Table K, we learn that the qualities of the girders 4, 5 and 6, are in the proportions of 1 : 1.26 : 1.77 or as 0.80 : 1.00 : 1.41. The open profile girder No. 5, is therefore better (on account of peculiarities of form and material) than girder No. 4, which consists of closed sheet-metal profiles and tubular struts, but not so good as the tubular girder No. 6. For the comparison of girders Nos. 7 and 8, the quality of the latter, at an increased length of 423 cm (13.88 ft.), is

$$G_x = 6800 \left(1 - \frac{1}{100}\, 21\, \frac{423}{253}\right) : \left(1 - \frac{1}{100}\, 21\right) = 6800\, \frac{0.65}{0.79} = 5500$$

Girder No. 8 is therefore better than No. 7. (See Part I, Section E.)

Table K. Quality of duralumin girders.

Compression girders (ball bearings).

No.	Designation	Fig.	Total flange cross-section F_o cm²	Girder height h and width b cm
1.	Strut with gusset End section = 0.5 middle section (about)	12 c 43.8	0.44	42 18
2.	4-flange girder with box frame	11	1.68	7 7
2a.	Ditto	11	21.00	25 25
3.	2-flange girder with brace wires	46a,b	0.88	24 6
4.	3-flange girder with closed sheet-metal flanges and tubular struts	47 d	2.70	22 25
5.	3-flange girder with U-flanges and flat strut-crosses	47 a 13	2,66	23.3 27.0
6.	3-flange girders with tubular flanges and struts	47 b 14	2.73	22.5 20.0
7.	Ditto	47 b 14	4.44	22 25
8.	Ditto	47 b 14	4.44	22 25

Table K. Quality of duralumin girders (Cont.).

Compression girders (ball bearings).

No.	Fig.	Girder length L_o cm	Division lengths t cm	$\frac{L_o}{i_o}$	Buckling load P_k kg	Wt. per running meter kg/m	Quality G_k kg/kg/m
1.	12c 43.8	31	9 4	39	880	0.148	5900
2.	11	120	10	40	4000	0.77	5200
2a.	11	425	35	40	52000*	10.00	5200
3.	46a,b	240=3×80	37	22	1400	0.52	2700
4.	47 d	260	58	22	3000	0.97	3100
5.	47 a 13	256	27	21	4500	1.16	3900
6.	47 b 14	256	42	22	6200	1.12	5500
7.	47 b 14	423	58	36	9000	1.71	5300
8.	47 b 14	253	58	21	12000	1.76	6800

* Buckling load calculated from other experiments.

Table L. Quality of duralumin girders
for resisting bending stresses.*
(knife bearings.) (Single load P_b in center of girders.)

No.	Designation	Fig.	Cross-section of compression flange F cm²
9.	2-flange girder with 2 brace wires	46 b	0.88
10.	4-flange girder with box frame	11 41.1	0.84
11.	3-flange girder with tubular flanges and struts	47 b 14	3.00

No.	Fig.	Girder length L_o	Girder height h and width b	$\frac{L_o}{h}$	Breaking load P_b kg	Wt. per running meter kg/m	Quality G_k kg/kg/m
9.	46 b	250	24 5	10.4	470	0.66	700
10.	11 41.1	100	10 7	10	600	0.80	750
11.	47 b 14	423	22 25	18.5	1300	1.80	720

* The strength of the struts was determined by bending tests, but the strength of the flanges was first determined by compression tests, because this method was simpler.

B. Assemblies.

1. Assembling methods.- Of the possible assembling methods, such as soldering, welding, screwing and riveting, welding is now employed only for small parts (Fig. 5); soldering, for fastening wires; and screwing only exceptionally, e.g., for fastening welded pieces. Riveting is the principal method of fastening. This is done cold, for strength and simplicity, and therefore results in a close-fitting of the rivet to the bore of the hole and does not require the friction between the united surfaces or a given shape of head, like hot riveting. The interval between the rivets is 2.5-3 times the diameter of the rivets and the distance from the edge of the sheet at least 0.5 (better 2/3) of the diameter of the rivet. The rivets are either hammered or pressed, either singly or in groups. Hammering produces, as compared with pressing, smaller counterpressures, but sometimes disagreeable concussions. Both hollow and solid rivets are employed. The former are used in sheet metal almost exclusively as eyelets for the application of great stresses (e.g., with wires). The process of riveting open profiles and sheet metal is generally known and needs no explanation. The riveting of closed profiles, however, needs to be briefly explained. The following five methods are employed.

1. Introduction of rivet through end of tube and clinching on the outside; mechanical and pneumatic introduction of rivets through the end of the tube. In Fig. 55, 1 is the tube for the

introduction of compressed air with the utilization of centrifugal force; 2 serves to complete the introduction and to hold the rivet firmly by means of the spring 3; the shoulder 4 for supporting the rivet head after turning the cylinder 5 (See cross section b); transmission of the clinching force, through introduced cylinders, to the opposite wall of the tube and thence to an outer head-cup or dolly; no weakening of the tubes.

2. Introduction of rivet (Fig. 56a) through an auxiliary hole (larger than the rivet head) opposite the rivet hole; weakening of tube up to 10%; introduction of "dolly" through opposite auxiliary hole.

In methods 1 and 2 the introduction of the rivet is troublesome, the outer head-forming is controllable, but oblique position of rivet is possible.

3. Introduction of rivet through rivet hole and clinching on inside by means of a dolly introduced through a large opposite hole (similar to 56a).

4. Introduction and clinching as above, the latter by means of a device working through the end like a wedge which, under simultaneous prsssing or hammering from without, renders it possible to increase the distance between the rivet shank and the opposite wall, corresponding to the length of the portion to be clinched (Fig. 57). There is no weakening of the tube. This method is employed by the Junkers Airplane Factory at Dessau.

5. Introduction of the rivet as before, introduction of dolly through a small opposite hole 2.5-3.5 mm (0.1-0.14 in.) wide, transmission of the force of the dolly through a cylinder to the rivet, 2-3% weakening of tube (Fig. 56b).

A plain cylindrical form suffices for the rivet tail. Methods 2, 3, and 5 have the advantage of rendering it possible to observe the inner rivet heads by means of interior illumination. In the other methods this is accomplished by the introduction of a mirror through the end of the tube. Methods 4 and 5 have proved very simple and, with the use of machines, have attained the quality and rapidity of open riveting.

2. Girder riveting.- With the exception of unimportant girders, every strut end must be fastened with at least two rivets. Care must be taken to have the mass of the dolly lie in the direction of the rivet shank. In mechanical riveting, it is better to have the machine stationary and the girder movable. The girder is then mounted on a beam with disks which hold the flanges in place (Figs. 54a and b). On the beam 1, which, e.g., for triangular girders, may have a triangular cross section, the struts 2, are distributed (according to their number and eccentricity) in individual movable forms 3 and flexibly pressed against the flanges 4, which are then drilled to correspond to the rivet holes already stamped in the struts. After one end of the strut has served as a pattern, it must be held fast by pins and then drilled through the other end. Several holes can

be drilled simultaneously. The rivets are first held by clamps or inserted just before the riveting process, before the girder is shifted to the riveting place. Complete elimination of hand work is not advisable, because this would necessitate a uniform division or a uniformly recurring set of divisions, which does not generally occur in airship construction. Otherwise, the shifting of the girder for drilling and riveting can also be effected mechanically. The cost of riveting airship girders is, moreover, relatively unimportant. For girders with inside struts, the process is simplified according to Fig. 53a, especially for tubular flanges. After finishing the riveting of strut 2 (Fig. 53a) the dolly 1 does not need to be removed, as in Fig. 53b.

Bent tubes are riveted according to methods 3 and 4, in which the introduced tool is adapted to the bend by a jointed or flexible shaft.

3. Joint connections.- The transmission of stresses between the connected parts should take place without moment, i.e., every cross-sectional part must, in so far as possible, in proportion to its size, be united by connecting members. For open profiles, one or two gussets of like profile are used and for every profile shank one or two special gussets, as customary. For tubular profiles, corresponding inner or outer tubes are employed. If long tubular girders are to be joined, the ends of the girders and the coupling sleeve all have large introduction holes for the purpose of riveting (Fig. 17 E). A full-strength joint can, how-

ever, be obtained by a suitable arrangement of the rivets, in spite of the weakening from the holes. On account of its length, it has the disadvantage that the end struts must, in order to avoid too great eccentricity, be riveted to the coupling sleeve. This necessitates a large introduction hole on its other end (to be previously reinforced by a perforated plate), through which hole, in riveting the strut, two rivets can be clinched as shown by Fig. 56a. This requires very accurate work. The difficulty of the strut connection and the riveting through introduction holes can be avoided, according to Fig. 17, A-D, by means of radially or tangentially flanged sleeves (C), form pieces (D), or tubular pieces (AB) and, as in ordinary joint coverings, by connecting each two sleeves by means of gussets or plates of sheet metal. In this way the connection is shortened and the weight reduced. The riveting is done the same as for open or half-open profiles and the girder can be fully riveted in advance, due to the shortness of the joint.

In employing strut crosses, we can, moreover, rivet two of the four arms at the time of making the girder and the other two simultaneously with the joint, without incurring the danger of breaking them off to such a degree as in the case of simple struts, on account of the great leverage ratio of their length to the distance between a pair of rivets.

At junction and assembly points, it sometimes happens that a profile is joined to a plate of sheet metal, where there must naturally be the least possible moment. Fig. 58 shows such joints for both open and closed profiles, c being an eccentric connection and therefore suited for only subordinate purposes. Either the sheet metal plate must be cut away (a) and hence made correspondingly rigid, or the profile must be slotted (b), or both methods employed. The tube can also be provided with a flange (e) to which anything can be easily riveted. Open profiles can likewise be reinforced by lining. In the figures, 1 denotes the profile to be joined; 2, the sheet metal part; 3, the flanged sleeve (see Fig. 18). The arrangement shown in Fig. 58e is employed for connecting the tubular members of the lattice or truss girder employed as the frame of an airship car (Fig. 19), with the aid of forged and welded parts.

4. Junctions.- The junction of girders with one another is effected chiefly by means of gussets, wall plates, straight and bent brackets and variously shaped sheet-metal parts, extensive use being made of flanging and corrugating for stiffening. (For junction parts, see Fig. 22.) The forms of the junctions are so many and varied, that only a relatively small number of them can be mentioned as examples. Four cases of junctions can be distinguished, namely:

1. For girders whose axes are all in the same plane;
2. For girders whose axes lie in two parallel planes;
3. For girders whose axes lie in two planes inclined toward each other and parallel to their line of intersection;

4. For girders or force-transmitting connections, which, besides conforming to the above specifications in No. 3, also extend in another third plane forming an angle with the line of intersection of the other two planes.

If the axes of girders of the same height intersect, only one girder can be continuous and the others must be joined to it.

No. 1, as illustrated by Fig. 59.- Plates 1 serve as connections for the brace-wires 2 (in the directions of the arrows). As compression members, they are flanged, where the supports are not frequent enough, and the longitudinal members, where not in immediate contact with the plates, are attached to the latter by gussets, so that the shearing forces are transmitted by the gussets from one wall to the other. In the case of great shearing stresses at the intersection point, transverse partitions must be introduced into the continuous girder for the continuance of the interrupted girder.

Case 1, as illustrated by Fig. 60, a and b.- One girder passes through the other, so that no butt-straps are required, but only the gusset-plates 1 for attaching the diagonal brace-wires 2. The gusset-plates are riveted to one girder and connected with the other by means of angle-plates 3. If the forces to be transmitted by the latter are large, U-profiles 4 are used. The girders abut inside or outside the junction point.

Case 1, as illustrated by Fig. 61 (Crossing of two triangular girders in a similar way to Fig. 60).- There are five fastening points, the upper point being connected with the four lower points by struts 6 forming a pyramid. The gusset plates 1 and 2 can be fastened to girder 3 only by means of angle-plates 4 and 5, because the girder flanges are U-shaped, though this would not be absolutely necessary for tubular flanges. Gusset-plate 2 is not shown in plan b (Fig. 61). The flanges are connected with one another (somewhat like Figs. c and d) by various fittings for preventing torsion and for transmitting the shearing forces from one flange to another, when rendered necessary by the interruption of the gusset-plates, as happens in case 1.

Case 2, as illustrated by Fig. 63.- The girder axes are shifted so as to allow the same girder height without interruption. Otherwise the arrangement is like Fig. 60.

Case 3, as illustrated by Fig. 62.- The arrangement is similar to Fig. 61. Both the buckling points of each flange, actually represented by arcs of 20 to 30 cm (7.87-11.81 in.) radius, are at the points of crossing the flanges of the other girder, so that the force components, resulting from the change in direction, can be communicated to the struts. There is a gusset-plate for the diagonal wires only on the under side and therefore a strut is introduced into the base plane of the strut pyramid. Under certain conditions, the bent flanges are strengthened (e.g., by being made thicker) in comparison with the flanges of the connecting girder, since it is not a question of the theoretical intersection of forces in a point. The abutting ends of the girder flanges outside the junction points generally allow this thicker construction which, moreover, is very desirable for bent girders with great bearing moment. In practice, the junction pieces are best made by themselves and the girders fitted to them in assembling the airship. Fig. 64 shows another form with only one bend of the flanges. There are here two side walls for the reception of the bending components and there is an upper framework of struts. If cast or forged parts are employed instead of the bent corner pieces, we have Fig. 64 without the bends. Instead of the walls, the pyramid struts and two lateral struts for stiffening the bends can be used, as shown in Fig. 65.

Case 4, as illustrated by Fig. 66a-d.- b is a cross-section; d is a plan; a and c are side views. The side walls 5 transmit the stresses of girder 3 (or of the bracing) of the third plane to the flanges of the girder 1 provided with a bend, and form, at the same time, the continuation of the strut system of girders 1 and 2. The flanges of girder 1 are held against the bend by the stamped pieces 4 and 12, of which the top 4 serves simultaneously to fasten the girder 3. To four other stamped pieces 6, riveted to the lower flange of girder 1, there are applied the forces of the diagonal wires 13. These forces are received and transmitted to the lower flange of girder

2 by the girder braces 7, the struts 14 and the auxiliary members 8-9. The three flange stiffeners 7 prevent any twisting of the lower flange of girder 1 through eccentric stresses on the gussets and stamped pieces. The upper flanges of girder 2 are attached to the downward bent flanges of the side walls 5, by means of the U-shaped sheet-metal pieces 10. They serve to stiffen the side walls with reference to one another and enable the use of one and the same U-piece for various inclination angles of girder 2 toward the perpendicular plane of symmetry of girder 1. Girder 3 is mounted by means of a rider, which is produced as a form piece or from riveted sheet metal and makes a pointed connection. Fig. 66c shows a rigid connection. Brace-wires are fastened, either instead of or along with girder 3 (Fig. 66a), by means of similar riders.

When two planes intersect each other at an acute angle, besides the above arrangement, that of Fig. 67 can also be used, in which, on account of their great length, the use of curved pieces was abandoned for acute angles. In (or practically in) their plane, there lie the upper flanges of girder 17, abutting the junction point. 13 are two cross-shaped, forged, stamped or cast form-pieces, which transmit the stresses of the flanges to the side-wall sheet 12 and also contain eyelets for the brace-wires, unless the additional moments, thus caused, necessitate the shifting of the corresponding eyelet directly to wall 12. The connection of the lower flange of girder 17 is made by the gusset 16, which also has eyelets for wires. Their horizontal stresses are transmitted through right-angles by means of wall 12 to the flanges of girder 18, and their vertical components, in so far as they are not offset by the flanges of girder 17 and the brace-wires 20, are transmitted by means of the angles 23 to the transverse wall 15. For this purpose, the angles 23 penetrate the walls 12. The brace-wires are designated by the numbers 19-20 and the connections of girder 17 by the numbers 21-22, which run somewhat according to Fig. 58. All the gussets are well supplied with lightening holes and flanged edges. The axes of all the girders and pairs of brace-wires intersect at one point. The stresses in the third plane are exerted on eyelet 24, but can act, however, in the opposite direction on form-piece 13 or on a rider set on the side walls 12 near form-piece 13. Instead of form-piece 13, there can be advantageously employed, in the plane of Fig. 67a or parallel thereto, a rider-shaped gusset attached to the side walls 12 by means of angle-plates. In addition to the flanges of girder 12, still other girder members or braces can be attached in the plane of said gusset. Fig. 20 shows another form of junction, which differs principally in the fact that the girders 17 have been turned 180° and that, instead of form-pieces, penetrating gussets of greater thickness are employed, after the manner of two folded hands.

In Fig. 66, the bent girder was so placed that its plane symmetry coincided with the plane of the third girder (No. 3). Consequently, in any desired position of this plane, the flanges of the girders 1 and 2 could not generally come into immediate contact, the height of girder No. 2, when it is to remain constant at various angles of incidence, being dependent on the height of girder No. 1, according to its greatest angle of incidence.

On the other hand, Fig. 21 shows an arrangement for tubular struts, where the plane of the lower wall of the bent girder is parallel to the axis of the straight girder inside the junction piece. With varying incidences the construction of the junction piece can remain the same, excepting that the bent members must be turned parallel to the third plane and that both the lower bent members must be shifted a little toward the upper bent member in the direction of the straight girder (as accurately computable), in order that the cross section of the bent girder may remain unchanged in the immediate vicinity of the bend, in spite of the turning. The turning of the tubes has no effect on the form of the connecting pieces, at least within broad limits. Such is not the case, however, in all other cross-sectional forms of the flanges. Moreover, the connecting parts for tubes (Fig. 22) are simpler than for open profiles, though the riveting is somewhat more difficult, since special devices are necessary. The stresses of the third plane are transmitted to the side walls by wires with the aid of an intervening distance or spacing tube. The brace wires are here attached to a junction gusset, which, by reason of its bend, is supported by the flange stiffenings. Under certain conditions, the gusset-plate is given, instead of the curvature, one or two edges (Fig. 68) and is riveted to the bent tube with the aid of lugs of various heights.

Here the point-shaped contraction of a girder should be considered, as required (e.g.) for the connection of girder 3 in Fig. 66, for the formation of a joint and for the simplicity of the connection.

Fig. 69, a and b, illustrates the principle of such a contraction. The bends in the flanges are supported by plates 1. The union of the three flanges and their extension to the opening 5 is accomplished by gussets 2, forming a pyramid (Fig. 69, a-d). In Fig. 69d, the flanges are connected directly to the pyramid, while in b and c they are connected to the pyramid by means of the sleeves 3. The transverse walls 4 have the eyelets 5 at the bottom. In b, these necessitate the slitting of one of the flanges. In c, the flanges are attached to the outside of the pyramid. In Fig. 69, e and f, two plates perpendicular to each other are employed instead of the pyramid, whereby one side wall of the girder is not bent, as in a, but the bend is replaced by a gusset (f). The eyelet lies in the axis of the girder. All the gussets are made of two thicknesses of sheet metal and are flanged.

As shown by the illustrations, the connecting of the girders with one another makes great demands on the shapability of the sheet-metal parts. Attention is further called to Fig. 22, in which 1 is a gusset plate; 2, a sleeve for connecting two tubes; 3, 4, and 5, pieces for connecting tubes to plates. It should also be noted that only small stresses, directed perpendicularly to one arm of a bracket, can be transmitted through the bend to the other arm without increasing or decreasing the angle. For great stresses, strong sharp-edged brackets or, still better, forged pieces must be used, through whose edges a greater moment is transmitted.

For attaching brace-wires, strips or ropes, only plain sheet-metal is required, which must be provided with steel eyelets, if wires are used. Fig. 73 shows various kinds of attachments, a being by means of high-grade steel wire, the end being twisted as close to the plate as possible, in order to prevent slipping. b is a similar attachment, in which the spaces in the spiral are filled with solder. c represents the attachment of a steel cable to a tube between two plates by means of a metal thimble and splicing. Ordinary wire cables cannot be used in airship rigging on account of their excessive elongability. The only slightly elongable Bowden cables can, however, be used for great stresses (with a strong pitch of the individual wires). Difficulties are involved in making wire attachments, since the wires, in order to obtain an initial tension, must be stretched, bent and fastened simultaneously. A similar process must be employed for cables and also for metal bands up to the bending. The stretching is done by means of a hoisting tackle or lever. The initial tension is necessary on account of the crookedness of the wire, the distortion of the bend, and the yielding of the structure, in order to prevent slackness and, for static reasons, to obtain a system under initial tension.

The steel bands are widened at their point of attachment for supplementing the cross section diminished by the attaching rivets or bolts and are attached to the gusset by means of two butt-straps for the avoidance of moments. The joining of wires by means of turnbuckles, as sometimes done on airplanes, finds no application on airships, on account of the great differences in the lengths. Where such differences do not exist, as in equally large side walls of the cabins or even of the rudders, turnbuckles can be very advantageously employed, especially for short lengths and great strengths, in order to facilitate variations in the tension, a task which must otherwise be accomplished by wrenches.

PART III - PLYWOOD CONSTRUCTION.*

A. Girders.

1. Cross-sections.- The cross-sections of the structural parts were principally formed out of basic elements similar to those employed in metal construction, as shown in Fig. 35. Row I shows two strips (Nos. 1-2), a gutter (No. 3), an angle (No. 4), a V-shaped spar (No. 5) and two U-shaped spars (Nos. 6-7). Row II shows cross-sections of plain-wood elements used for strengthening or connecting plywood parts. Combinations of the elements in rows I and II give the structural parts whose cross-sections are shown in rows III-IX (Nos. 14-35). Thereby the plain-wood elements Nos. 8 and 10 are employed in the cross-sections of rows III-V, which they stiffen against buckling. Element No. 9 serves as the basis for row VII. Elements 8, 12 and 13 serve for the construction of Nos. 32-34 (row IX).

Row III contains T-sections made up of strips and angles; row IV, gutter sections made from gutter No. 3 and strips 2, 8 and 10; row V, U-sections in combination with strips; row VI, U-sections composed of profiles 6 and 7 and perforated strips No. 2; row VII, box-sections composed of plywood and plain-wood strips; row VIII, closed plywood sections; row IX, cross-sections of connecting parts (partitions or struts), which serve to connect spars after the manner of rows III-VIII. These cross-sections are employed both as independent supporting parts and in the construction of open-work girders.

* Compare "Zeitschrift für Flugtechnik und Motorluftschiffahrt," 1921, No. 8.

2. Girder construction.- The structural parts, especially the girders, are built with the aid of the above elementary forms, thus rendering it possible to obtain sufficient strength for the various purposes, with the minimum weight. A distinction is made between main and subordinate girders. The former are only open-work girders of large dimensions, while the latter are of smaller dimensions, either open-work or plain, and serve for smaller stresses (rows III, VI, VII). Thus, e.g., the girders of row VI serve as supports for plywood walks (as likewise the metal girders of Fig. 16b); the ones in row VII, as wall posts; and No. 32 of row IX, as light ribs (Compare Fig. 1 in No. 8 of "Zeitschrift für Flugtechnik und Motorluftschiffahrt," 1921).

Main girders are generally constructed of parallel booms or flanges with connecting struts, the same as metal girders, and are given various forms, according to whether they are to be subjected to bending stresses in one or two directions, to buckling stresses, or simultaneously to both buckling and bending stresses, or whether their free length is subjected to a one-sided support or bracing in one direction, while being unsupported in the other direction.

Fig. 36, A-K, shows the cross-sectional forms of main girders. The upper diagrams represents, in each instance, a section at right angles to the flanges, while the lower diagrams are sections perpendicular to the struts. The numbering of the elements is the same as in Fig. 35. Fig. 36 gives end views of girders A-K. The arrows indicate the direction of least strength.

A is a double-T girder with box strut 34.

B " " " " " " V-strut 35.

C " " " U " " perforated side walls.

D " " " U " " I-strut 32.

E " " " tube " " flat strut 38,
and transverse members 32.

F " " " " girder with perforated sides 37.

G " " " " " " " struts 33.

H " " triangular " " " sides 37,
and transverse members 32 glued to their webs.

I is a four-T girder with oblique perforated strut walls 32 and perforated side walls 37.

K is a four-tube girder with strut walls 33 and side walls 37 strengthened by transverse strips 8.

Girders A-G are intended for small loads in the direction of the arrows, but for great loads in the plane of the struts, this being more especially true for girders A-B than for girders C-G. The strength in the direction of the arrows can be increased by bracing (as in the case of metal girders) till it equals that in the main direction. This is done, e.g., in the cases of the longitudinal girders L, the intermediate transverse frames or rings Z (Fig. 24), and the walkway posts (Compare "Z.F.M.," 1921, No. 8, Fig. 9).

The strength of the girders E to G, when they are made wide enough, is nearly equal to that of the girders H to K. The latter were used for the main rings H of the airship in Figs. 24 and 28 and for the longitudinal members O and L of the walkway. They have a condensed form and are especially suited to withstand buckling and bending stresses in two directions perpendicular to each other. Regarding the difference between strut and box formation of the girder walls and the advantages and disadvantages of triangular and quadrangular girders, the same principles apply as already mentioned for metal girders. In contrast therewith and due to the weakness of the plywood angles, transverse walls or bulkheads must be introduced at relatively short intervals, these being glued to the webs of the perforated side walls. In the practical production of girders, the above-mentioned parts are sometimes extended or supplemented by small connecting parts. For example, in girders D, the arms of a U-profile are held together at certain short intervals by gluing on web-plates s (Fig. 23, D2). The struts receive, at certain points, an extended connecting surface, corresponding to the stresses to be undergone and the strength of the glue. The same holds true for the girder flanges as, e.g., in Fig. 23, for girders A and B and in Fig. 35 for the plain-wood strips 9. In D1 special bracing strips are employed for connecting the struts and flanges. Much depends on having connecting surfaces sufficiently large and rightly dimensioned, which can be thus obtained, chiefly because the glued connections must also transmit moments which act in and transversely to the surfaces.

The characteristics of plywood girders, including the dimensions, breaking loads, and qualities of differently built girders, are given in Tables M and N. These tables show that, for buckling stresses, the T-girders 1 stand last, but that the rectangular girders 4 stand first. For bending stresses, the double U-girders 6 and 7 occupy first place, the double T-girders 1 last place, and the four T-girders 8 the next to the last place. It should also be noted that the U-girders are relatively rigid and very wide, so that the flange under compression is especially well protected against buckling by the flange under tension. This does not hold good, to the same extent, for the double-T girders. The four T-girders have great rigidity, but are not braced for great transverse stresses (compression girders). In other respects, the same principles apply as for metal girders.

Table M. Quality of plywood girders.

Compression girders (ball bearings).

No.	Designation	Fig.	Total flange cross-section F_o cm^2
1.	2-flange girders with T-flanges and 2 lateral braces on each flange	36 A 23 A	13
2.	2-flange girders with U-flanges and 1 lateral brace on each flange	36 D 23 D	11.90
3.	3-flange girders.	36 H 23 H	16.56
4.	4-flange girders with T-flanges	36 J 23 J	25.30

No.	Fig.	Girder length L_o cm	Girder height h and width b cm	Buckling load P_k kg	Wt. per running meter kg/m	Quality G_k kg/kg/m
1.	36 A 23 A	259 = 3 x 86	24 6.50	2400	1.011	2380
2.	36 D 23 D	262	24 10	4500	1.118	4025
3.	36 H 23 H	259	20 23	3460	1.34	2580
4.	36 J 23 J	411	23 23	6620	1.95	3400

Table N. Quality of plywood girders for resisting bending stresses (knife bearings).

(Single load P in center, except for girder 6.)

No.	Designation	Fig.	Cross-section of compression girder F cm
5.	2-flange girder with T-flanges and 2 lateral braces on each flange	36 A 23 A	7.5
6.	2-flange girders with U-flanges, load uniformly distributed	36 D 23 D	8.4
7.	Ditto	36 D 23 D	7.5
8.	4-flange girders with T-flanges (no struts to resist bending)	36 J 23 J	11.75
9.	2-flange girders with tubular flanges	36 E 23 E	10.00

No.	Fig.	Girder length L_o cm	Girder height h and width b cm	$\frac{L_o}{h}$	Breaking load P_b kg	Wt. per running meter kg/m	Quality G_k kg/kg/m
5.	36 A 23 A	250	24 6.5	10.4	510	1.52	340
6.	36 D 23 D	356	24 10	15.2	720	1.52	472
7.	36 D 23 D	250	24 10	10.4	1100	1.53	722
8.	36 J 23 J	250	23 23	10.9	746	2.03	368
9.	36 E 23 E	220	19.2 5	11.6	630	1.50	422

B. Connections

Glue serves as the connecting medium between wood and wood, especially the water-tight varieties. Other varieties, however, can be made water-tight for a long time. A glued surface, according to the quality of the glue, will stand a shearing stress of 20 to 40 kg/cm², but only 3 to 7 kg/cm² tension at right angles to the surface. The parts to be glued must be clamped firmly together, in order to avoid hollow spaces and for good penetration of the glue. The joint connections are made like those of open metal profiles and do not require consideration. It need only be remarked that all connecting strips and brackets can be easily tapered in thickness, thus giving an advantage, in respect to weight and strength, not so readily attainable with metals. In girder breaks the damaged portion can be easily cut away and another substituted by oblique gluing (Fig. 72) without loss of strength, chiefly because, in the case of wood, due to its great flexibility, the excessive stress is mostly restricted to a single weak point. Girders can also be very easily reinforced, even outside the workshop, by gluing on strips or gussets of either plain or plywood.

Junctions are also made similarly to metal, but there are two conditions to observe.

1. Profile members of wood (Fig. 35) can be made with an original curve, but cannot be bent at will in the construction

shop, after the manner of the sheet-metal parts in Fig. 22. Hence we are restricted to the use of straight or only slightly bent parts. Good junctions can, however, be made with wood, though with a somewhat less open appearance than those made with metal.

2. Great stresses, like those of the brace-wires, e.g., cannot be applied directly to plywood, even with the use of an eyelet, but they must first be received by sheet metal and then transmitted to the plywood as shearing stresses by means of hollow rivets, since otherwise the stress would be too great for the wood and the connecting surface too small. The distance between the hollow rivets (or eyelets) must be three times their outside diameter of 7-20 mm (0.276 - 0.79 in.) and the distance between such a rivet and the edge of the wood must be at least twice its diameter. The best materials are duralumin sheet-metal parts with steel eyelets, since the application of a great stress at a single point and a large distribution surface with a relatively small weight are thus rendered possible. Such a metal sheet is undesirable when in contact with wood on both its sides, since the wood structure is thus interrupted.

The already-mentioned general case in metal construction, of the location of the axes in three planes, with the girder flanges over one another and girders of equal height, requires, e.g., an arrangement like Fig. 70, in which a four-flange and a double-U girder are crossed and a strut (or girder) is applied at a certain angle to the line of intersection of the two-girder planes. The girder 1 has its walls 3 inside the joint and the double metal sheet 7, provided with flanges and an eyelet, is attached to both walls. Both these walls 3 are attached to the walls 4 of the girder 2 by means of angles, led through the lower strip 6 and glued to the lower flange of 1. The strip 6 lies on girder 2, is connected with the lower flange of girder 1 by the angle 8 and has four sheet-metal plates 9 for attaching brace-wires. The walls 3 and 4 transmit simultaneously the stresses of the struts in the side walls in which they lie. Strip 5 is designed to receive and transmit in its plane the stress components from the sheet-metal gusset 7. The gusset transmits these forces by means of the flanges 10 or through the medium of angle-pieces. In a similar manner, the crossing of non-abutting girders of other types is accomplished and adapted to very great stresses.

Simpler and easier and hence preferable is the abutting of two girders of like height (Fig. 25, a and b). Two four-flange and two double-U girders are generally connected to two parallel plates, whose projecting double laps serve for gluing two T-flanges of the four-flange girder and their simple broader laps for fastening the U-profiles of the other girder. The latter has a straight axis and the former has a bent axis, which follows from the curve of the plates. The girder flanges, after introduction and gluing between the two plates, are also connected, by means of angle-pieces, with the plates or with the four-flange profile inside the joint and the shearing stresses of the struts are likewise transmitted through angle-pieces to the side walls, visible at b, which are themselves connected together by a sheet-metal piece for the further transmission of the shearing stresses. This sheet-metal part serves for joining the stresses of the third plane and has, for this purpose, an eyelet through the upper plate, which eyelet here lies in the middle plane of the four-flange girder and can transmit stresses, in the direction of the girder, through lateral sheet-metal angles to the plate. The gussets for the brace-wires (eyelets visible) lie on the outer side of the junction plates. In "Z.F.M.," 1921, No. 8, Figs. 11 and 29-35, there is shown the junction of four girders. Fig. 13 in the same article shows a similar junction of five girders, of which the fifth (a walkway post) forms a butt-joint. In Fig. 26 of the present article, the four-flange profile is replaced by a double-T profile, and the two junction-point walls by a single transverse wall, on which is set the girder P of the third plane. Its connecting plates are slotted for admitting the connecting plates of the other two double-T girders and the gusset resting on them is left open, so that the shearing stress of both girders can be combined by means of wooden angle-pieces. Such a joint is much stronger than one made by riveting on sheet-metal angles. The open-work gusset serves for attaching brace-wires in a plane, formed by the girder L, running straight through, and the girder P, lying in the third plane. Fig. 27 shows the junction of five girders, lying in the three planes, I, II and III. Brace-wires are attached in a fourth plane.

Fig. 28 shows an older and different type of construction. The girders cross each other in contact with an intervening junction plate. The eyelet for the wires of the third plane is in a gusset projecting from the bending point of girder H, this gusset being connected to two transverse walls by means of a sheet-metal plate lying in the central plane of the girder. The transverse walls transmit their stresses to the side walls of the girder by means of downward-bent flanges and hollow rivets (Fig. 28). The intervening metal plate is extended, where necessary, into the lower girder, in order to relieve the latter of any great bearing stress. Ordinarily it suffices to glue the lower girder to the junction strips and stiffen it with the usual transverse wooden walls. Sometimes the gluing is reinforced by duralumin bolts. Individual forces, which must be transmitted from metal to wood or from wood to wood (e.g., from girder to girder in the case of Fig. 28) not as shearing but as tensile forces, likewise necessitate the use of bolts, like Fig. 57, whereby Plate 1 is made rigid and attached to the stress-receiving transverse wall 3 by means of a sufficiently large glued area 2 and wood linings 5, without causing the angles 5 to spread.

In wood construction, especially at junction points, inaccuracies of fabrication and subsequent alterations do not cause so much trouble as in metal construction, since, as already mentioned, the desired shape can always be obtained, with only a slight increase in weight, by gluing on the appropriate wooden pieces.

Likewise, after the completion of a wooden junction, recesses can be cut. In metal girders, on the contrary, such a course would be attended with difficulties.

PART IV - CONCLUSION.

In conclusion, it may be remarked that the photographs, when not made before the war, are of experimental parts, since, according to the stipulations of the Treaty of Versailles, all structural parts actually used or intended for use had to be destroyed.

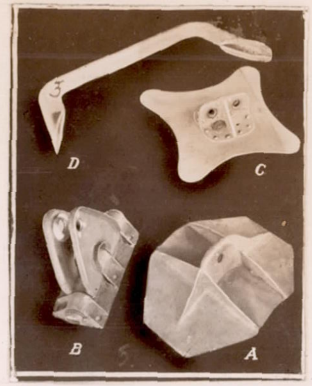
In the foregoing, the building materials and the metal and plywood construction methods employed in rigid airships have been treated from the viewpoint of adapting the materials to the forces to be withstood. As has been seen, these materials (plywood, duralumin and steel) form an ascending series (corresponding to the size and stresses of the airships), as do likewise the structures of open and closed profiles. A far more difficult problem than the adaptation of the materials is the determination of the axial stresses of the whole system. This forms a field of its own, extending beyond the limits of this article, and can be only briefly referred to here. The calculation of the airship frame as a single braced girder, on account of its great static indeterminateness, requires more time and labor than is available in practice. Hence the system is preferably divided into units, such as the main or outer frame, the stiffening transverse frames (main rings), walkway and tail unit. The stresses and distortions of the main frame are first established on the basis of simple and verifiable assumptions regarding the rigidity relations. Then the stresses of the individual members are computed with the aid of the data thus obtained. The results can be employed for correcting the original assumptions and the computations then repeated. This is not necessary in most cases, since the results are generally accurate enough. The amount of computation work is still considerable, since the individual objects are still many-fold (e.g., 20-fold) statically indeterminate and then the most different static and dynamic load conditions of the airship have to be considered. Moreover, as mentioned at the beginning, the bending stresses undergone by the different girder members must be determined. The publication of these very interesting experiments must be reserved for a later date.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

Fig. 1 Interior of hull

a) Cross of flat strip
b) " " tubes
c) Single strip
d) " tube
e) Stamped tie
f) Double-tied strut
g) Box form
h) Stamped tie

Fig.4 Girder members



A,B, Steel; C, Dural; D, Aluminum

Fig. 5 Stamped and forged pieces.

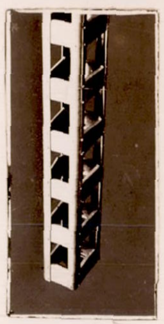


Fig. 11 Girder with box forms.

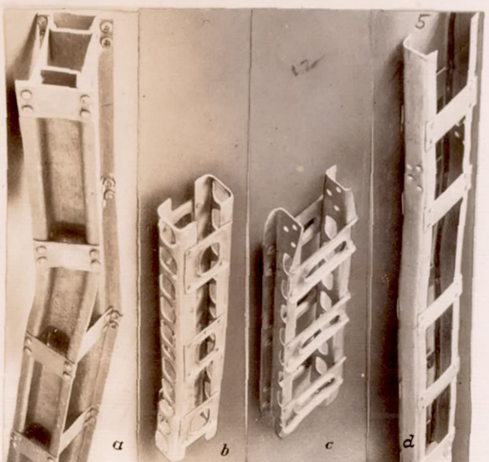


Fig. 12 Lattice girders

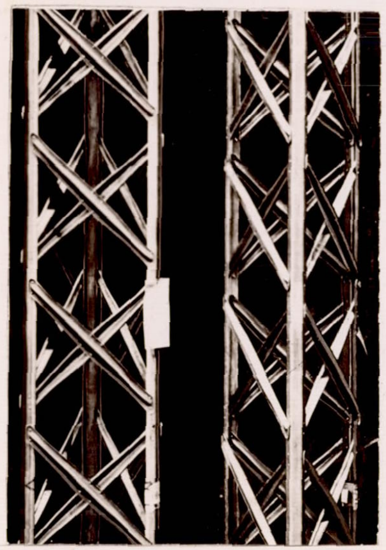


Fig. 13 Open girders with flat struts.

a) Without transverse crossing of struts.
b) With transverse crossing of struts

Fig. 14 Tubular girders

Figs. 1,4,5,11, 12,13&14.

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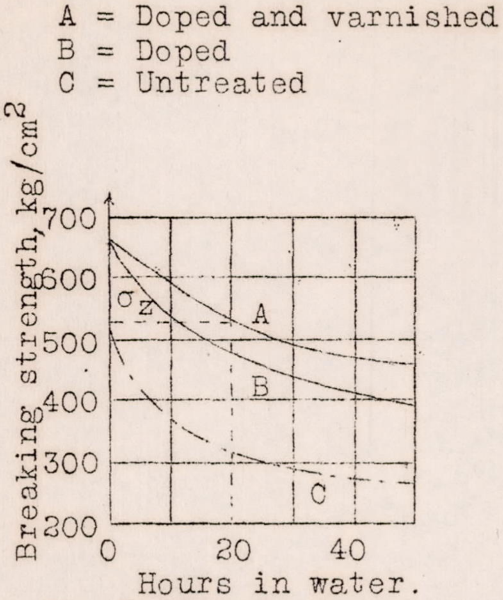


Fig.2 Effect of doping on strength of wood.

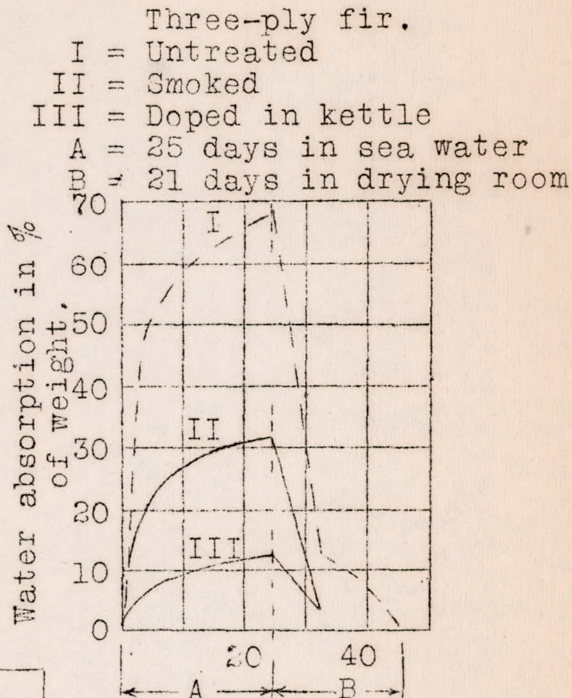


Fig.3 Effect of doping on moisture content of wood.

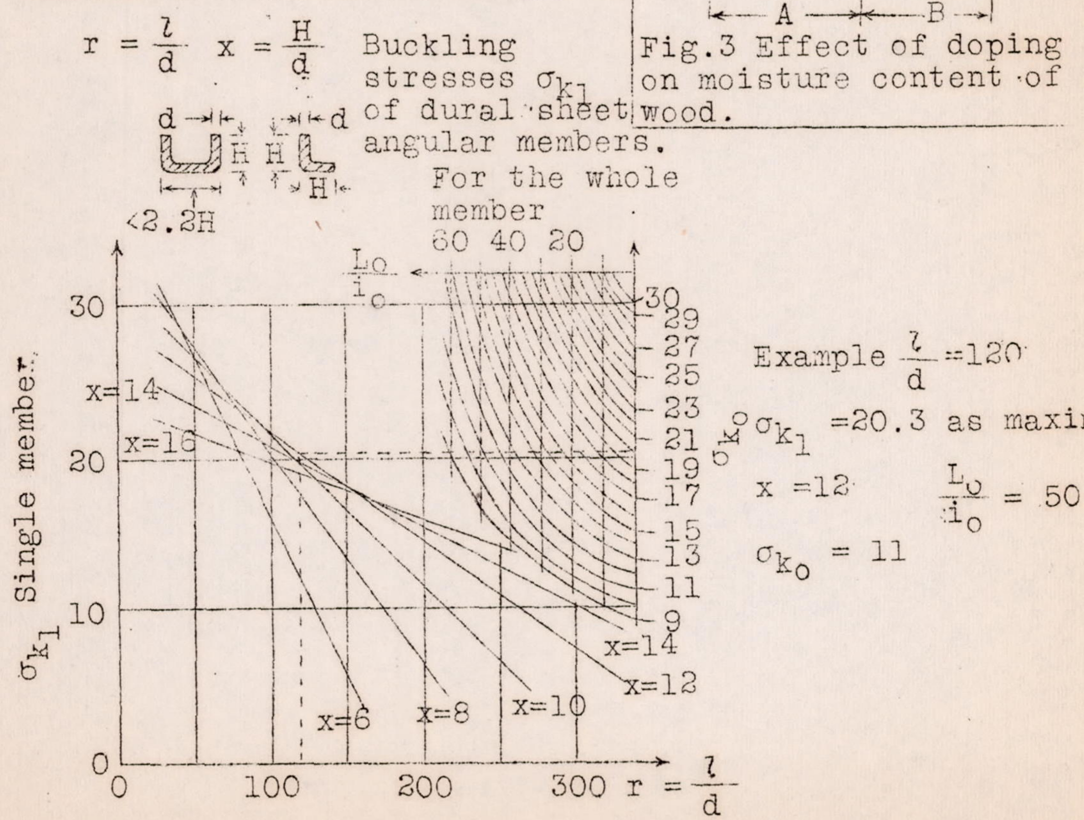


Fig.6 Determination of buckling stress of a girder.

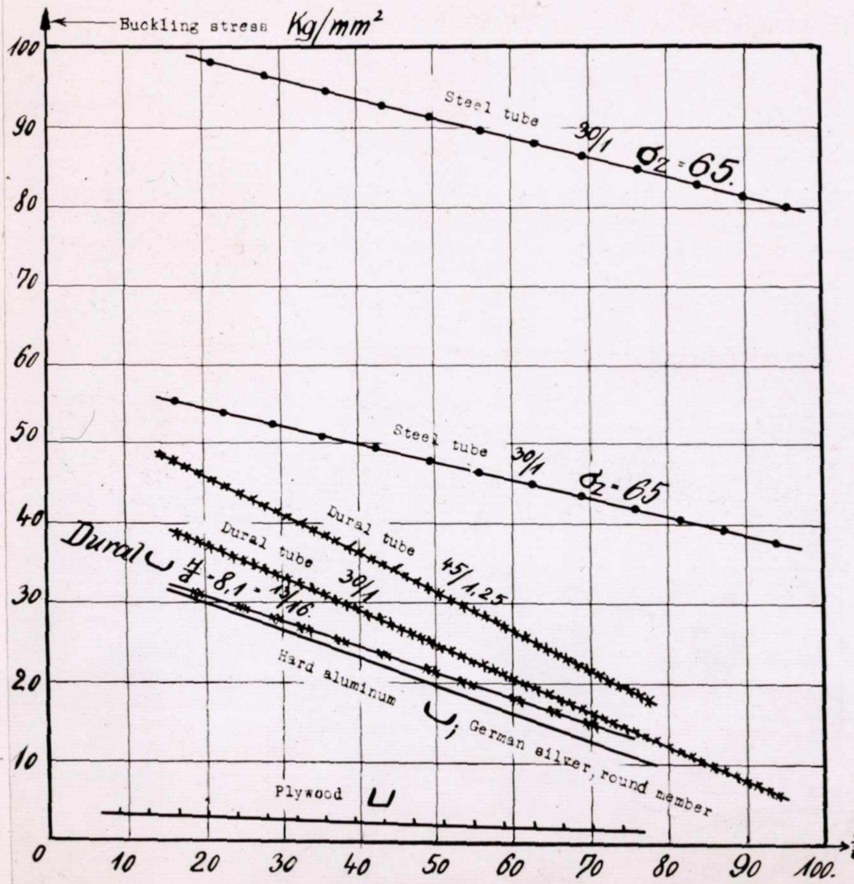
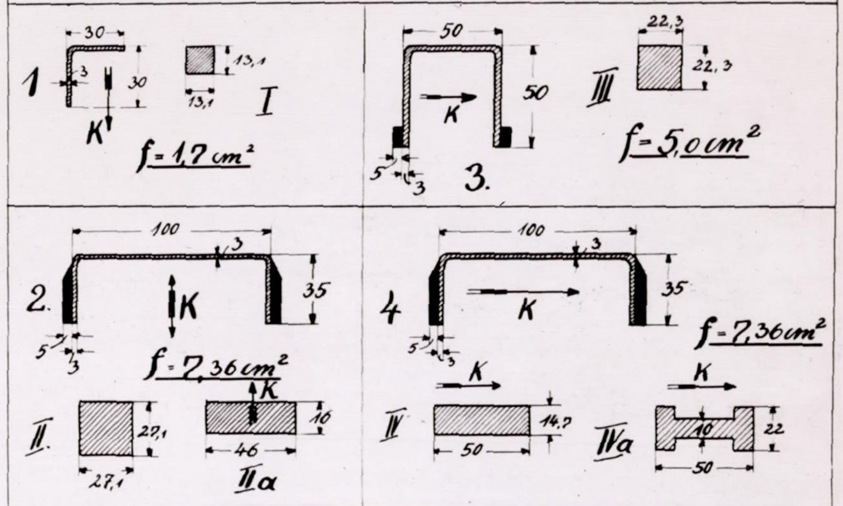


Fig. 7 Buckling curves

Buckling loads of plywood and solid wood members of like weight.



Arabic numbers refer to plywood; Roman numbers to solid wood of like cross-section area. Arrows K show expected direction of buckling.

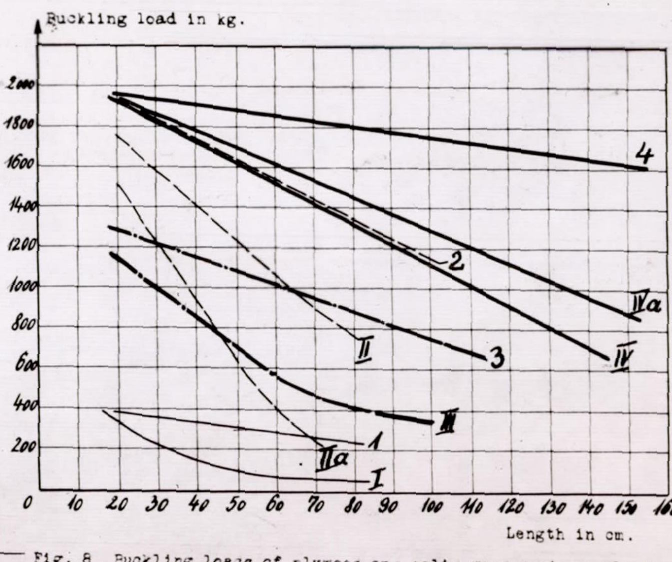


Fig. 8 Buckling loads of plywood and solid wood members of like weight.

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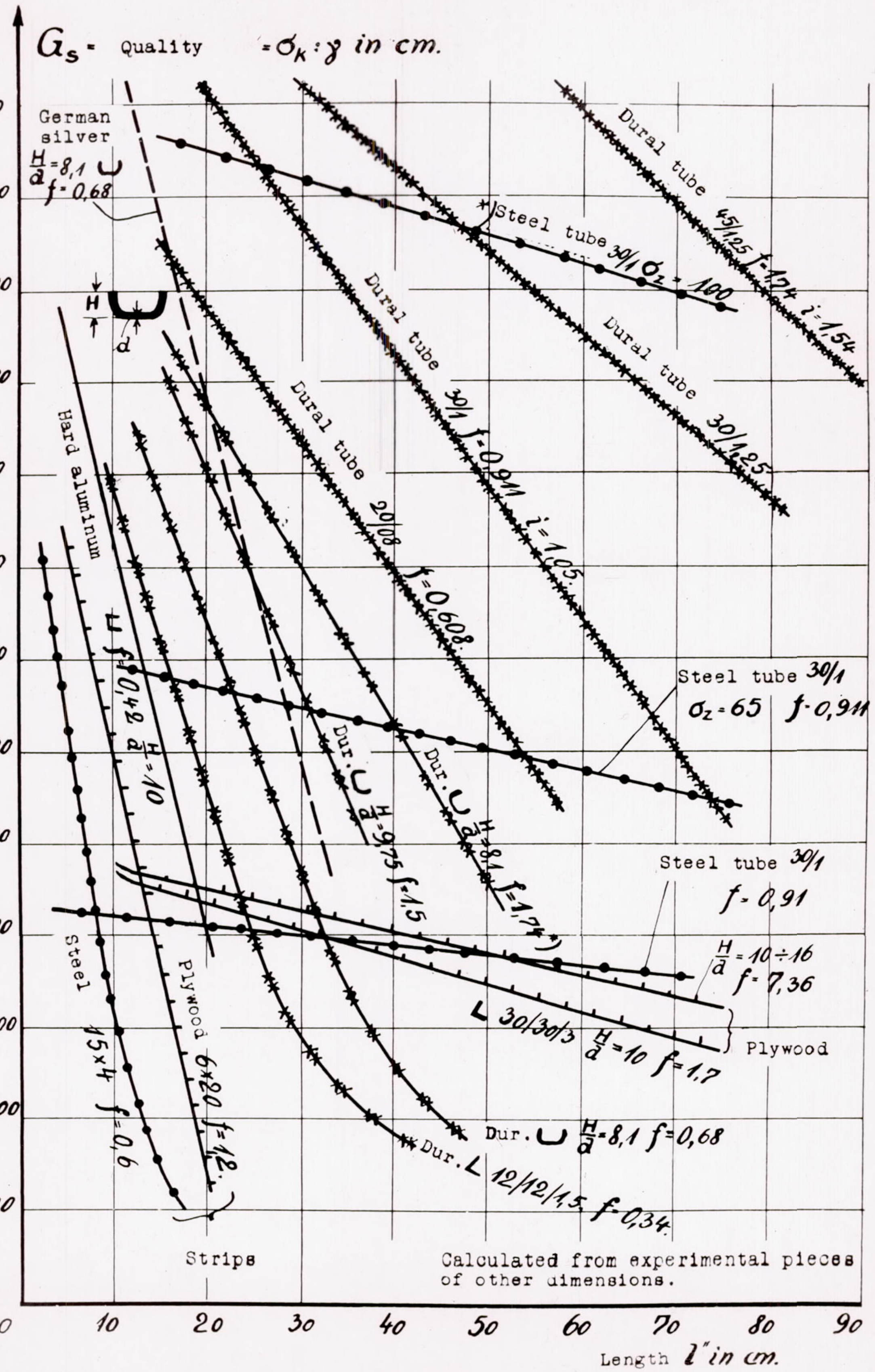


Fig. 9 Quality of member.

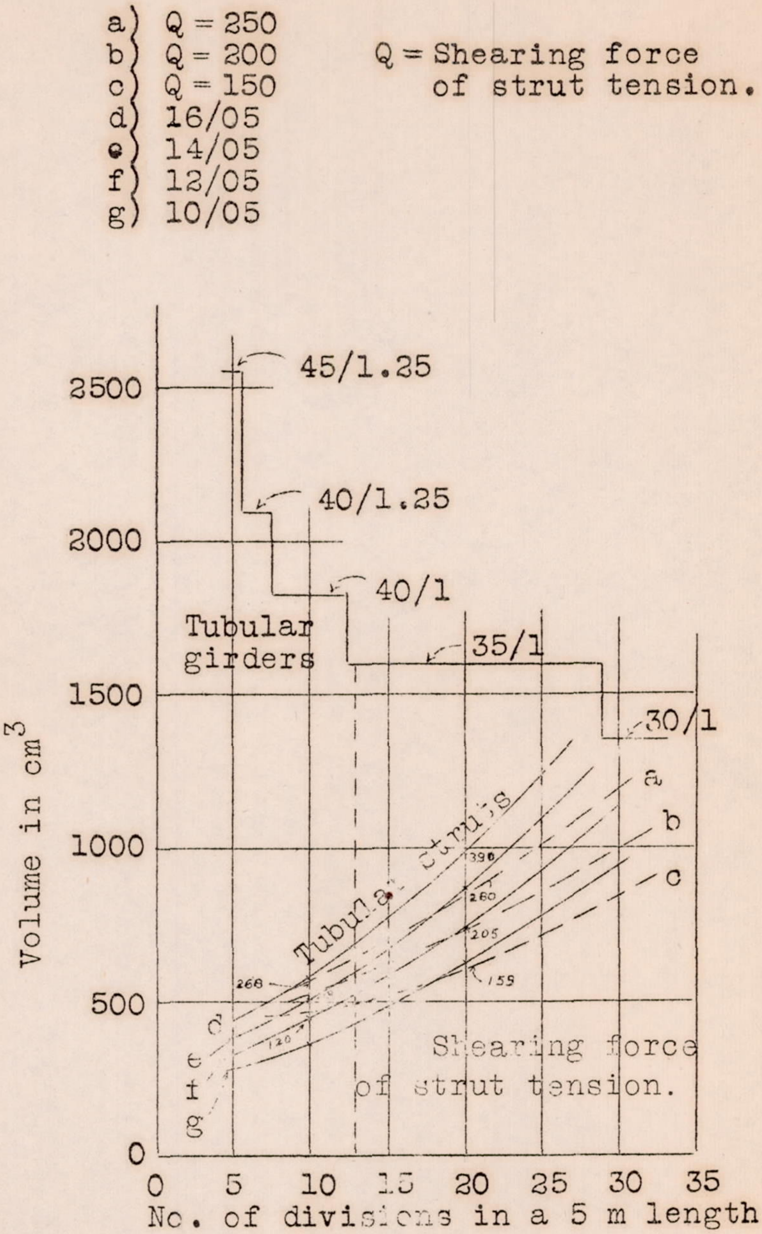


Fig.10 Determination of minimum volume of a girder.

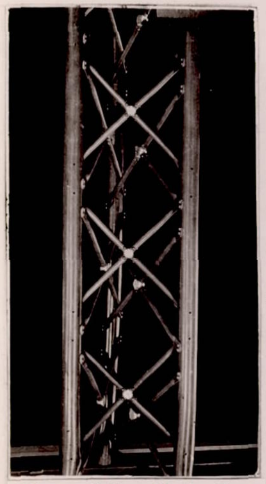
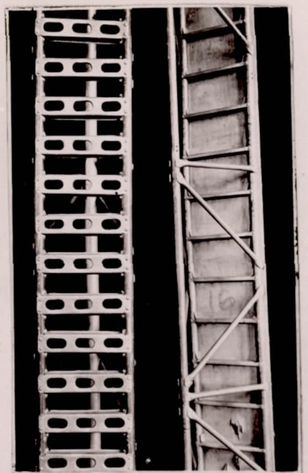
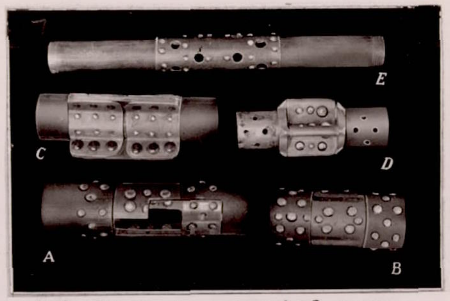


Fig. 15 Tubular girder with cross-struts.



a) Sheet-metal
b) Ply-wood
Fig. 16 Tubular foot-way girder.



A(B) With tangential projections.
C,D With radial projections
E With sleeve.
Fig.17 Tubular butt-joints.

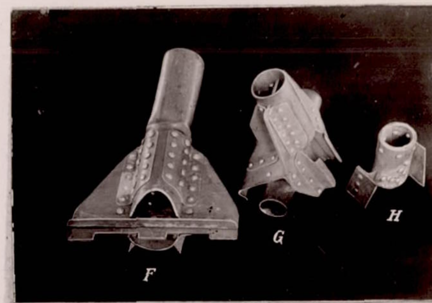


Fig. 18 Transition from a tube to a plate.

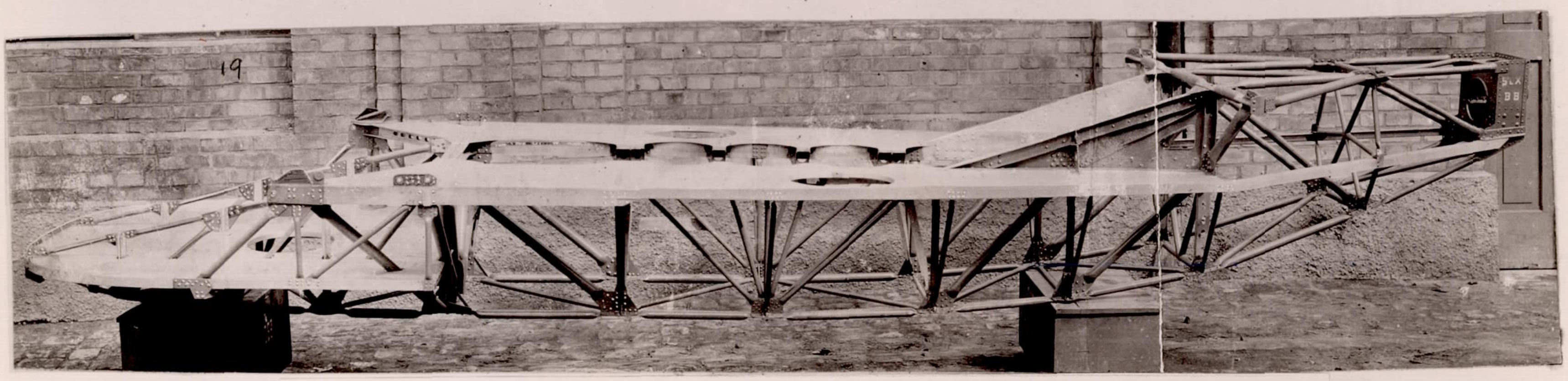


Fig. 19 Airship car frame of steel tubing.

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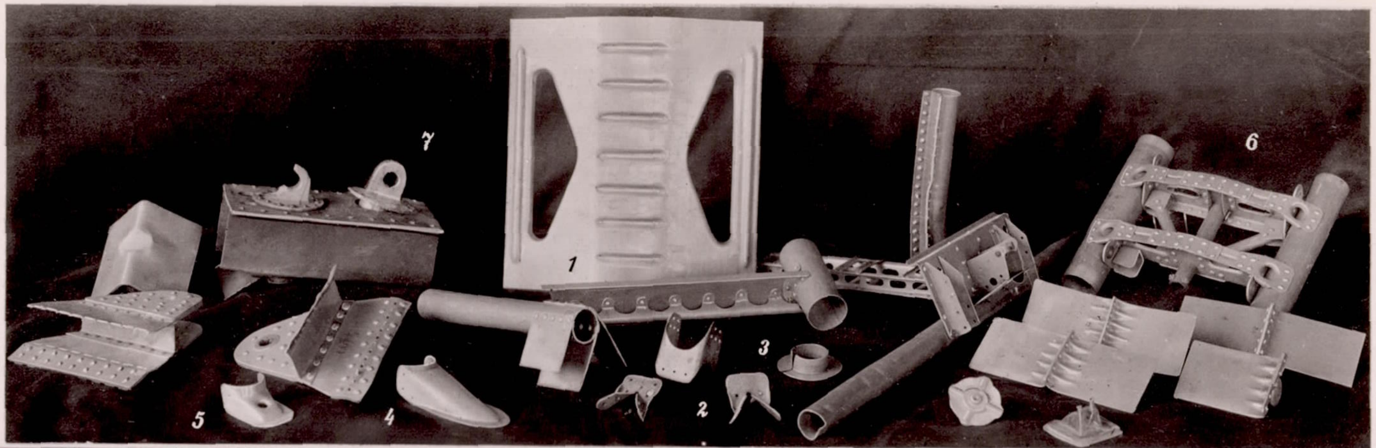

1) Corrugated gusset
2) Pieces for connecting two tubes.
3)
5) For connecting tube and plate
6) Sheet-metal bracing of girder for heavy loads.
7) Solid eyelet

Fig. 22 Junction parts (Dural)

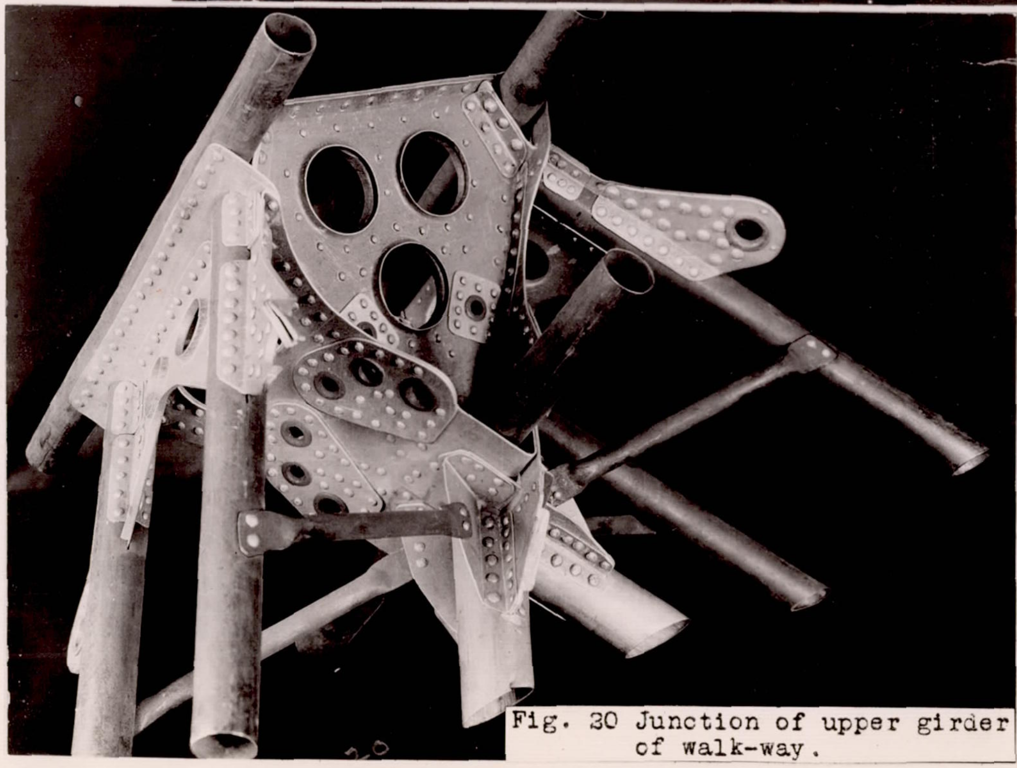

Fig. 20 Junction of upper girder of walk-way.

Fig. 21 Junction of braced ring (main transverse)

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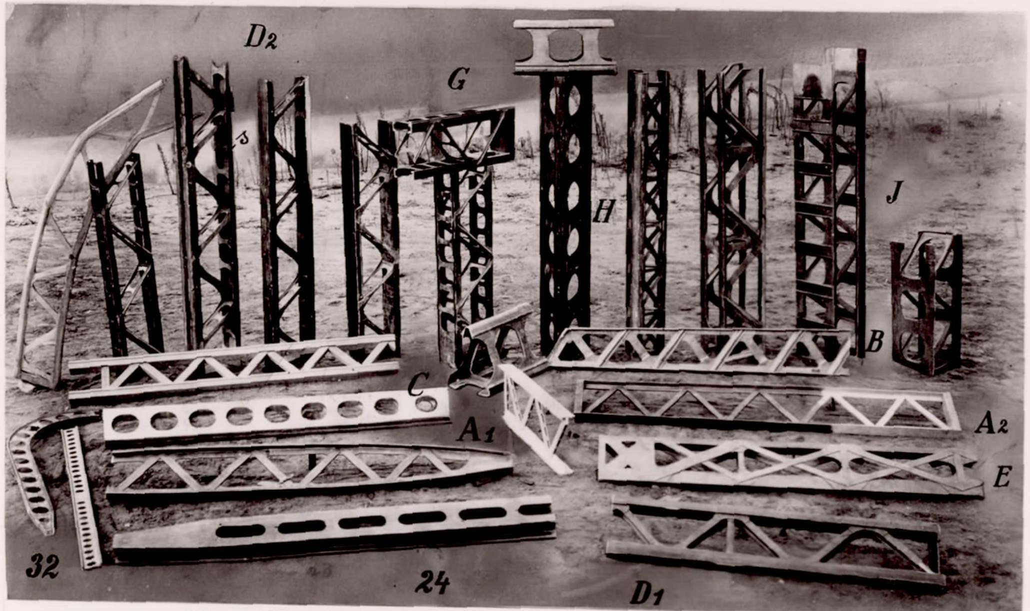
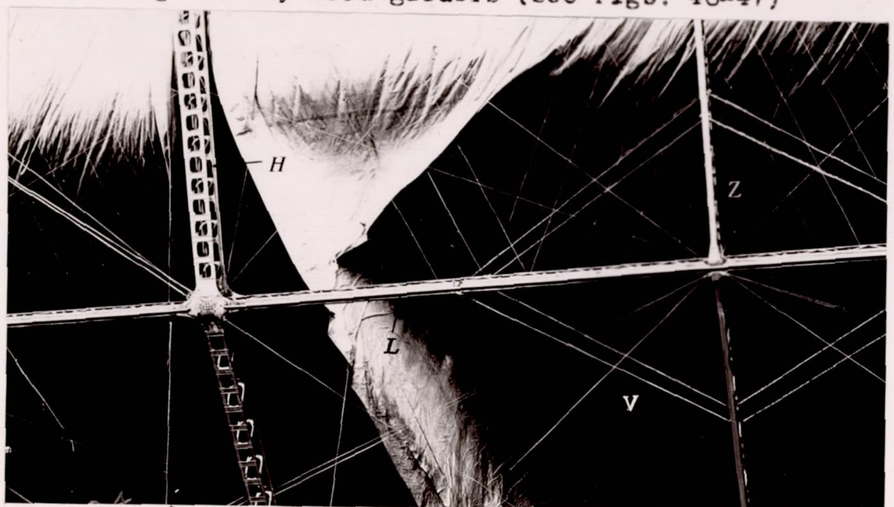


Fig. 23 Ply-wood girders (See Figs. 46-47)



H) Main ring. L) Longitudinal girder.
Z) Intermediate ring. V) Brace-wires.
Fig. 24 Portion of airship frame, without cover.

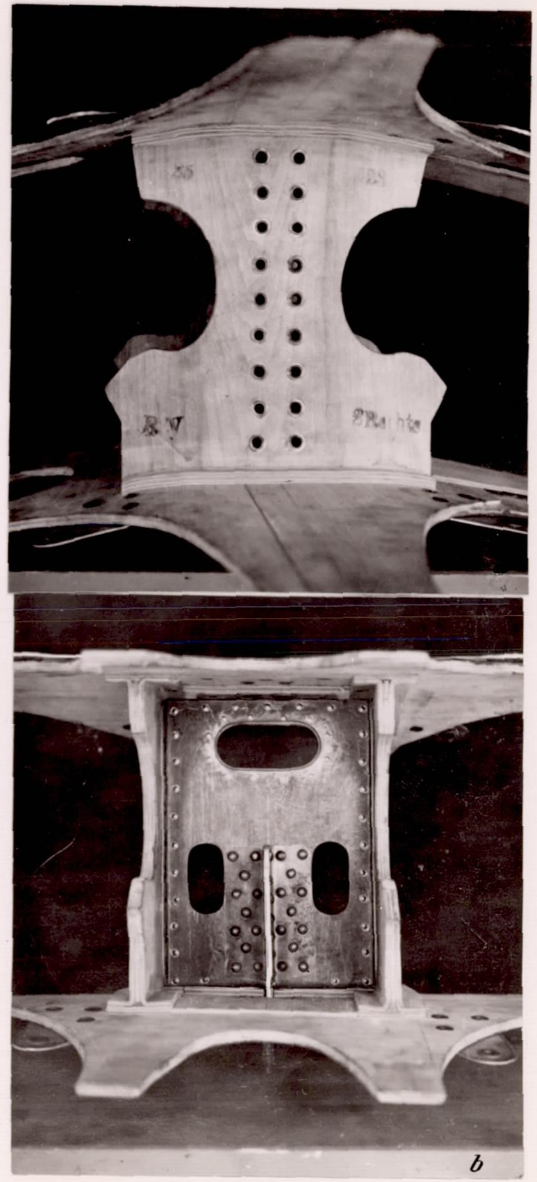


Fig. 25 Junction of main ring

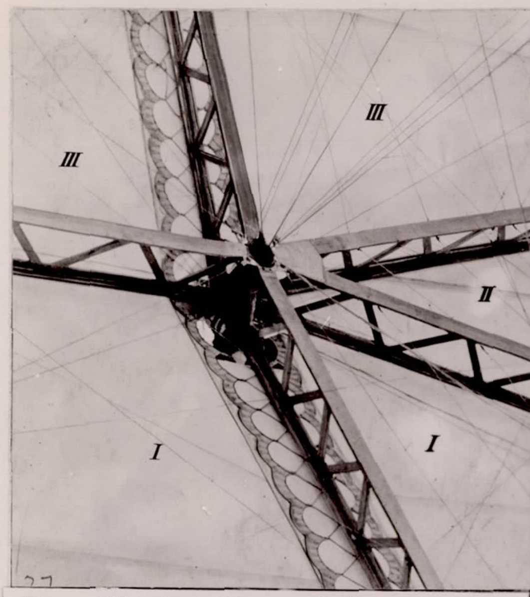
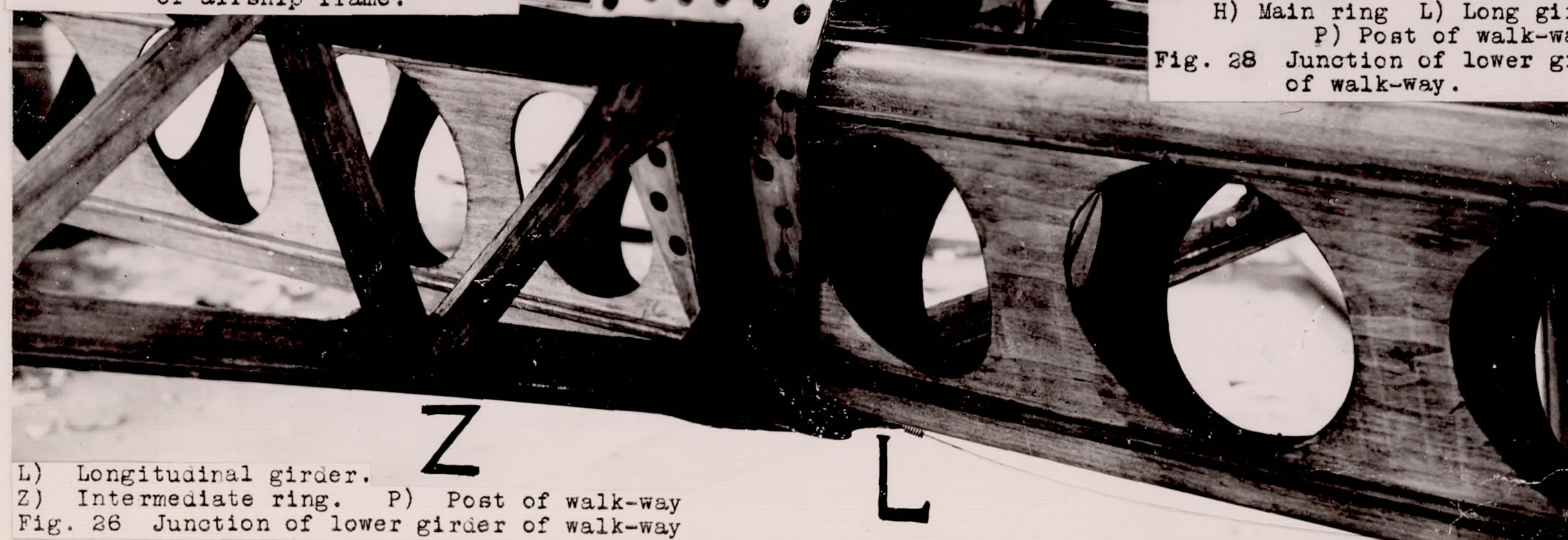


Fig. 27 Junction of five girders of airship frame.

H) Main ring L) Long girder
P) Post of walk-way
Fig. 28 Junction of lower girder of walk-way.



L) Longitudinal girder.
Z) Intermediate ring. P) Post of walk-way
Fig. 26 Junction of lower girder of walk-way

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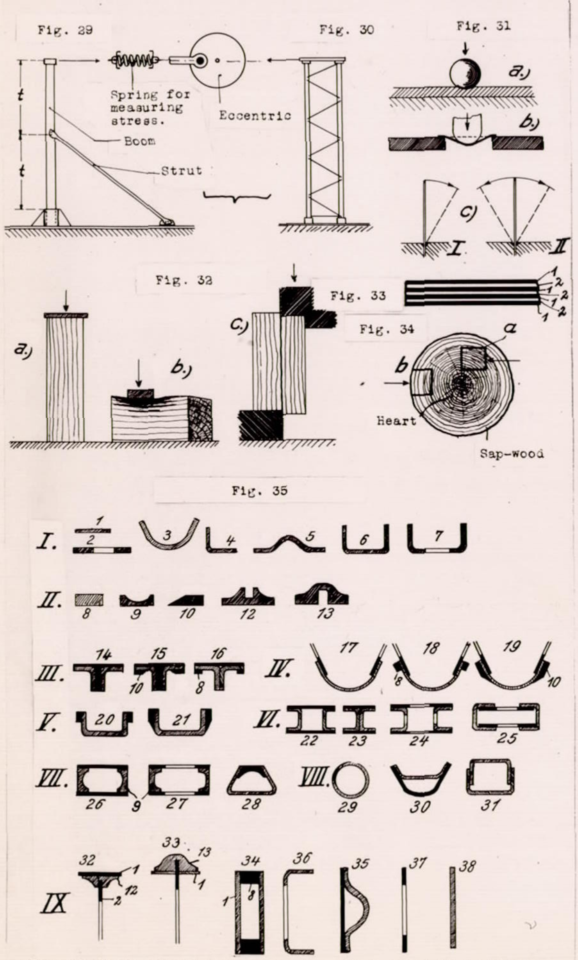


Fig. 29-31 Experimental arrangements Figs. 32-34 Wood structure
Fig. 35 Plywood sections

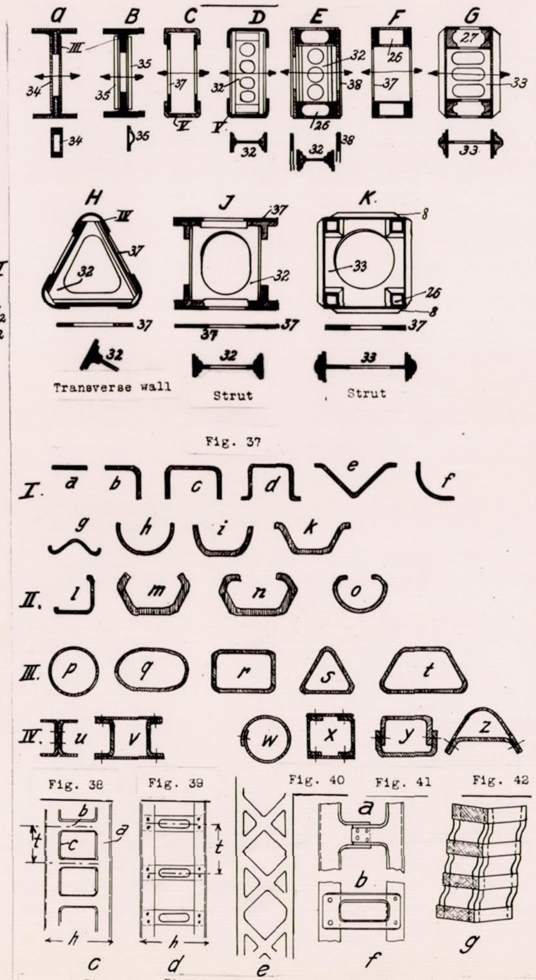
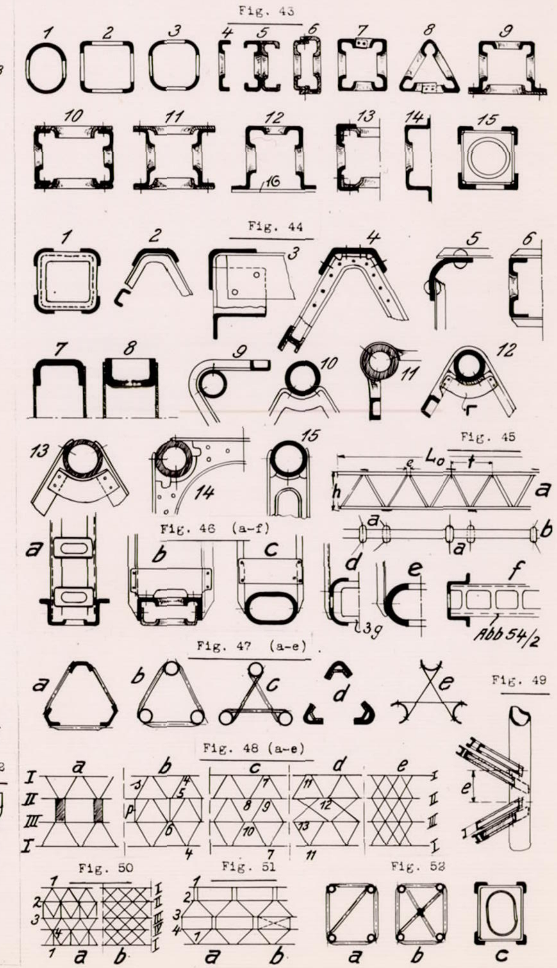


Fig. 36 Plywood girders Fig. 37 Dural sections
Fig. 38-42 Dural girders



Figs. 43-52 Dural girders

N. A. C. A. Technical Memorandum No. 313 Figs. 29 to 52

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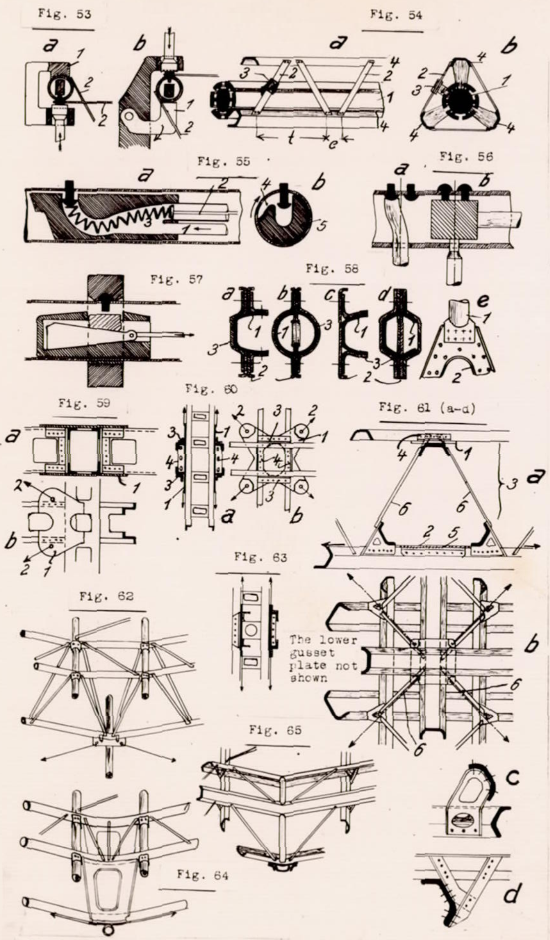
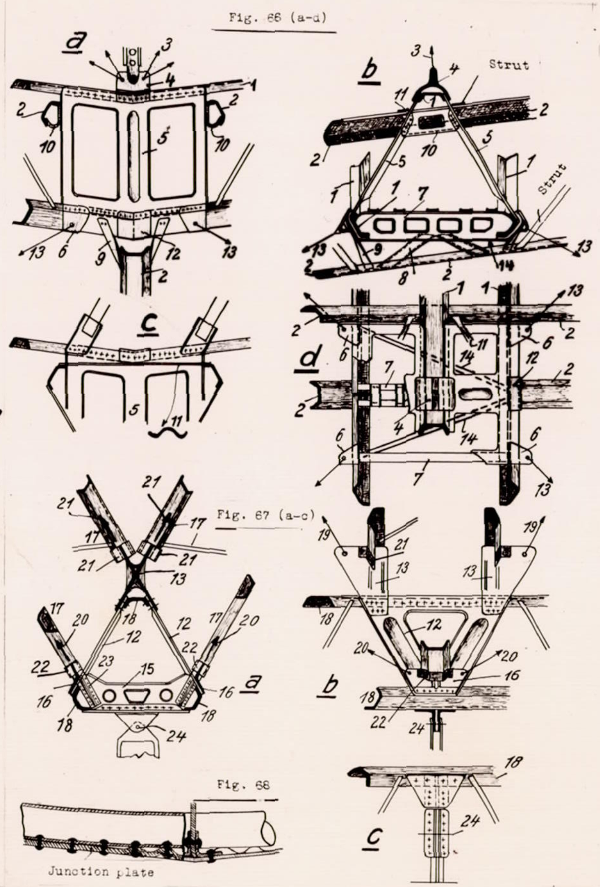


Figs. 53-57 Riveting of tubes. Fig. 58 Transition from plate to profile. Figs. 59-65 Dural junctions.



Figs. 66-68 Dural junctions.

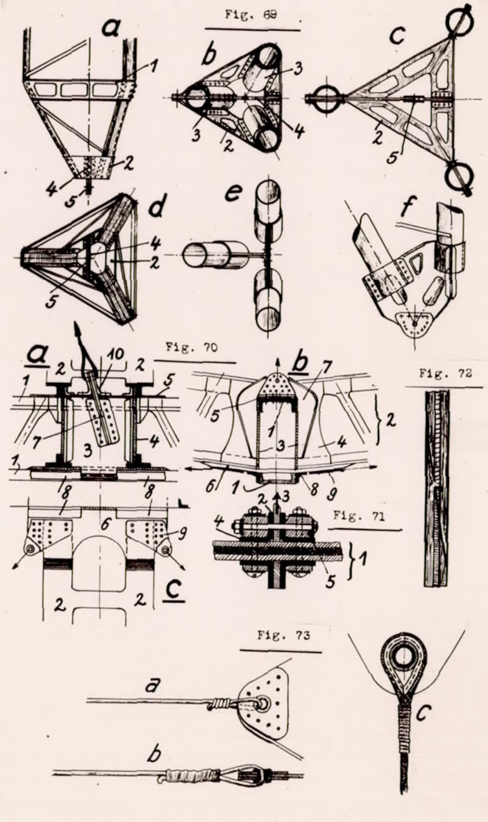


Fig. 69 Dural junctions. Figs. 70-71 Plywood junctions. Fig. 72 Splicing plywood. Fig. 73 Wire attachments.

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